LAWRENCE LIVERMORE NATIONAL LABORATORY, HIGH ENERGY LASER FACILITY
(Nova Building)
(Building No. 391)
7000 East Avenue
Livermore
Alameda County
California

HAER No. CA-2323

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

BLACK AND WHITE PHOTOGRAPHS

HISTORIC AMERICAN BUILDINGS SURVEY
Pacific West Region
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U.S. Department of the Interior
909 1st Avenue, 5th Floor
Seattle, WA 98104

**LAWRENCE LIVERMORE NATIONAL LABORATORY,**
**HIGH ENERGY LASER FACILITY**
**(Nova Building)**
**(Building 391)**

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| **Location:** | South of North Outer Loop Road in the north central portion of Lawrence Livermore National Laboratory (LLNL), 7000 East Avenue, Livermore, Alameda County, California |
| **Present Owner:** | U.S. Government, Department of Energy, National Nuclear Security Administration |
| **Present Use:** | LLNL National Ignition Facility (NIF) laboratories and offices |
| **Significance:** | The national High Energy Laser Facility, later also known as The Nova Building (Building 391) is historically significant for the breakthrough experiments it housed in Inertial Confinement Fusion (ICF) laser research. From 1985 to 1999 the Nova laser was the largest in the world and the tests demonstrated the feasibility of achieving ICF using lasers, setting world records in power and neutron generation. |

## Part I. HISTORICAL INFORMATION

### A. Physical History[1]

1. **Date of erection:**
   Building 391 High Energy Laser Facility (Increment I)
   Designed: January 1, 1974
   Construction Begun: August 1974
   Building Completed: 1976
   Shiva Laser Fired: November 18, 1977
   Dedication Ceremony: April 28, 1978

   Building 391 Nova Addition (Increment II)
   Designed: 1978
   Construction Begun: May 1979
   Building Completed: 1983
   Nova Laser Fired: December 19, 1984
   Dedication Ceremony: April 1985

2. **Architect:** Norman Engineering (Increment I); Albert C. Martin Architect and Engineers (Increment II).

   Norman Engineering designed and built Increment I of Building 391 (known at the time as the High Energy Laser Facility). It housed the Shiva laser and was built as a dedicated laser facility. Norman Engineering was a Los Angeles firm owned by Norman Fink. Fink built many government laboratory buildings including the wind tunnel at Tullahoma, Tennessee. Norman Engineering acted as the architect-engineer and construction manager for the project.

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[1] The following documents were used in determining the correct dates of the physical history of Building 391. They are listed in the order of the information presented. "High Energy Laser Building 391, Lawrence Livermore Laboratory California, Vicinity Map-Site Plan," 1974, PLZ 74-391-001JA; Alexander J. Glass and Kent L. Cummings, eds., *Laser Program Annual Report-1975,* UCRL-50021-75 (Livermore, CA: Lawrence Livermore Laboratory, 1975), 14; Philip E. Coyle, ed., *Laser Program Annual Report-1976,* UCRL-50021-76 (Livermore: Lawrence Livermore Laboratory, 1977), 1-9; Charles Bender and Brian D. Jarman, *Laser Program Annual Report- 1977,* UCRL-50021-77 (Livermore: Lawrence Livermore Laboratory, 1978), 2-2; "Dedication: Shiva High Energy Laser Facility," April 28, 1978, NIF Project Files, Lawrence Livermore National Laboratory Archives; Michael J. Monsler and Brian D. Jarman eds., *Laser Program Annual Report-1978,* UCRL-50021-78 (Livermore: Lawrence Livermore Laboratory, 1979), 2-123; Lamar W. Coleman and John R. Strack, *Laser Program Annual Report-1979,* UCRL-50021-79 (Livermore: Lawrence Livermore Laboratory, 1980), 1-13; Charles D. Hendriks, M. Louise Rufer, and Peter W. Murphy eds., *Laser Program Annual Report-1983,* UCRL-50021-83 (Livermore: Lawrence Livermore Laboratory, 1984), 1-6; "Nova Laser Facility is Completed," *Energy and Technology Review,* July 1985, 40; and M. Louse Rufer and Peter W. Murphy, *Laser Program Annual Report-1984,* UCRL-50021-84 (Livermore: Lawrence Livermore Laboratory, 1985), 2-1.

Albert C. Martin Architect and Engineers designed Increment II, the Nova Addition to Building 391. The Albert C. Martin architectural and engineering firm was established in 1906 and partnered on projects with Los Angeles's foremost architect, John Parkinson. The three-generation family enterprise specialized in seismic techniques. The Martin firm was responsible for much of the distinctive architecture in Los Angeles, including Grauman's Million Dollar Theatre (1917), St. Vincent de Paul Church (1925), the Los Angeles Department of Water and Power Headquarters (1965), Arco Plaza (1970), and the Sanwa Bank Plaza (1990). Martin's most famous project was the Los Angeles City Hall (1928), the tallest building of its time towering 452 feet above the city. The building's tower was designed as an independent structure anchored to reinforced concrete and resting on stiff clay. The Martin firm's expertise in seismic engineering was particularly important in the construction of the Nova facility, which demanded stringent vibration limits for its successful operation. The resulting building design does not represent high-style architecture but was a state-of-the-art laser facility at the time it was built.

3. **Original and subsequent owners, occupants, uses:** The building has always been owned by the U.S. Government, as part of one of the laboratories of the Atomic Energy Commission (AEC) and its successor agencies (currently the Department of Energy/National Nuclear Security Administration (DOE/NNSA)). Building 391 originally housed lasers for the LLNL ICF Laser Program and continues to support that effort with offices and laboratories for NIF.

4. **Builder, contractor, suppliers:**
   Norman Engineering (Increment I) was both the architect/engineer and the construction manager for the project.

   Albert C. Martin (Increment II) was the architect/engineer and Kaiser Engineering was the construction manager for the project.

5. **Original plans and constructions:** In 1974, Norman Engineering, a Los Angeles firm, completed the design for Increment I of Building 391; construction was completed in 1976. Increment I had approximately 66,000 square feet. It was a high-bay structure built of pre-cast concrete, cast-in-place concrete, and painted steel panels over a steel frame.[2] The interior included a basement and main floor with a viewing gallery accessible as a second floor outside of the laser bay. The building had five

[2] "High Energy Laser Building 391, North and South Elevations," 1974, PLZ74–391–034JA, LLNL Plant Engineering Library (hereafter PEL); and "High Energy Laser Building 391, East and West Elevations," 1974, PLZ74–391–035JA, PEL.

main spaces: a main laser bay, target room, energy storage area, laboratory area, and building support systems.[3]

6. **Alterations and additions:** In 1983, Increment II, the Nova Addition, was completed. It was designed by Albert C. Martin and building construction was managed by Kaiser Engineering. It was a concrete and steel addition very similar to the original building design. It added 106,000 square feet to the east side of the building and included an additional laser bay, target room, master oscillator room, and rooms for laboratories and mechanical equipment.

   Additional alterations included: the renovation of the Shiva laser bay into a target room for the Two-Beam, an extension of two arms of the Nova laser, in 1985; a seismic upgrade in 1990; and the conversion of the Two-Beam target bay into an optics laboratory for NIF in 1997.

**B. Historical Context:**

Completed in 1976, Building 391 originally housed the Shiva laser. It was remodeled and renovated, including a large addition, between 1979 and 1983, to accommodate the Nova laser. The Nova laser was part of LLNL's ICF Program, the sixth in a line of ever more powerful neodymium-doped glass lasers developed to achieve a controlled thermonuclear reaction in the laboratory. On December 19, 1984, the Nova laser came on line, firing all ten beams into the target chamber.[4] In 1986, Nova produced ten-trillion neutrons during a fusion burst, setting a world record. The Nova laser was the largest fusion laser in the world in its day. It operated for nineteen years and demonstrated the feasibility of obtaining ICF via lasers. The ICF Program at LLNL grew out of a combination of weapons design and testing, Controlled Thermonuclear Reaction (CTR) research, and early laser research.

1. **Early LLNL History**

   In September of 1952, the AEC established LLNL as a second nuclear weapons design facility. E. O. Lawrence and Edward Teller, physicists affiliated with the Manhattan Project during World War II (WWII), advocated the founding of a second laboratory to accelerate the design and production of a thermonuclear weapon, arguing that this was the next advance in atomic weaponry. Neither Lawrence nor Teller felt that Los

[3] University of California Lawrence Livermore Laboratory, *Laser Program Annual Report, 1976*, UCRL–50021–76 (Livermore: Lawrence Livermore Laboratory, 1976), 1.6; "High Energy Laser Building 391, First Floor Plan," 1974, PLZ74–391–027JA, PEL; and "High Energy Laser Building 391, Basement Floor Plan," 1974, PLZ74–391–027JA, PEL.

[4] *Laser Program Annual Report-1984,* 2-1.

Alamos National Laboratory (LANL)[5] was working aggressively enough to achieve this goal. Their argument was well-received within the AEC, as the Soviet Union had detonated its first atomic weapon in 1949 and a nuclear arms race element was added to the early Cold War. American policymakers, fearing the potential actions of an enemy armed with nuclear weapons, determined to deter their use by significantly increasing the U.S. stockpile.

Although the primary goal of LLNL was to design and develop a hydrogen bomb, Herbert York, the first director, insisted on incorporating non-weapons research into the mission of the laboratory. The four missions he articulated for LLNL were designing thermonuclear weapons, providing diagnostic measurements for weapons tests for LANL and LLNL, developing CTR for power sources, and basic physics research. He hoped to attract the brightest young scientists in the country and felt that there should be breadth and depth of research options beyond nuclear weapons investigations to attract them.[6]

The U.S. tested its first successful thermonuclear device in 1951 at Enewetak Atoll. The early atomic weapons split atoms of uranium or deuterium, a process called fission, resulting in a large release of energy or explosion. A thermonuclear weapon builds on the fission, using the initial fusion release of energy to combine, or fuse, elements of deuterium, resulting in an even greater energy release. Shortly after the development of the hydrogen bomb, U.S. scientists became interested in harnessing the energy released in a thermonuclear explosion.

The benefit of the successful achievement of this difficult scientific exercise would be to free the world from reliance on costly and finite sources of energy like fossil fuel. If scientists could replicate thermonuclear processes in precisely controlled laboratory conditions, energy from fusion could be extracted from one of the world's cheapest elements—deuterium, a heavy hydrogen found abundantly in the ocean.[7]

Fusion research funded by the AEC and its successor agencies was used both to pursue fusion for energy uses and to create environments in which to test nuclear weapon designs.

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[5] The current names of the national laboratories are used throughout this report to avoid repeated explication of titles.
[6] University of California, Lawrence Livermore National Laboratory, *30 Years of Technical Excellence* (Livermore: Lawrence Livermore National Laboratory, 1982), 4; and Herbert York, "Making Weapons, Talking Peace," *Physics Today* (April 1988): 44–45.
[7] *30 Years of Technical Excellence*, 32.

**2. Fusion for Energy Applications**

In 1951, the AEC established a classified CTR program, code-named Project Sherwood, to explore the possibility of harnessing fusion for energy applications. The AEC funded work on Project Sherwood at multiple sites. Lawrence Berkeley National Laboratory (LBNL), LANL, Oakridge National Laboratory (ORNL), the Naval Research Laboratory (NRL), New York University, Massachusetts Institute of Technology (MIT), Princeton University, and LLNL participated in the search for controlled nuclear fusion.[8]

The basic requirements established to produce and control fusion for energy were fourfold:

- To heat a small amount of fusion fuel until it combusts—at hundreds of millions of degrees.
- To confine the super-heated fuel in a chamber (without touching the walls) long enough for the fusion energy released to exceed its combustion temperature.
- To convert the energy released into electricity or heat.
- To replace the combusted fuel and remove the waste product.[9]

The main approach to CTR research in the 1950s and 1960s used the concept of magnetic fusion. AEC scientists endeavored to develop a special magnetic field produced by magnetic coils that surrounded the fusion combustion chamber. The magnetic field prevented the super-heated fuel, or plasma, from contacting the chamber. Several promising concepts were pursued, including the pinch, the stellerator, and the magnetic mirror.[10] LLNL had one of the largest magnetic mirror programs in the country. LLNL scientists and engineers designed a series of magnetic mirror machines that achieved many CTR goals, reaching thermonuclear temperatures for brief periods of time.

In 1970, the national CTR program and LLNL became interested in using lasers to achieve fusion. This process used a laser to heat small pellets of deuterium until they imploded, causing plasma dense and hot enough to produce a thermonuclear reaction. The AEC began funding both laser and magnetic approaches to fusion.[11]

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[8] Amasa S. Bishop, *Project Sherwood: The U.S. Program in Controlled Fusion* (Reading, Mass.: Addison-Wesley Publishing Inc., 1958), 20–21.
[9] *30 Years of Technical Excellence*, 32.
[10] Ibid.
[11] Joan Lisa Bromberg, *The Laser in America, 1950-1970* (Cambridge, MA: The MIT Press, 1991), 238.

### 3. Laser Fusion Research at LLNL

LLNL had been interested in lasers (devices that could produce short pulses of intense light) since their invention by Theodore Maiman at the Hughes Research Laboratory in Malibu, California, in 1960. A subsequent breakthrough called Q-switching (storing up laser energy over a long time and releasing it in a short burst) by Hellwarth and Hughs at the same laboratory led LLNL to develop their own laser research department. In 1962, Ray Kidder, a physicist at LLNL, persuaded John Foster, then director, to establish Q-Project "to investigate the potentialities of this new technology to produce fusion."[12] After the project had been running for a year, Kidder and Associate Director Ted Merkle formally apprised Major General Betts of the AEC's Division of Military Applications of LLNL's progress in laser research.

Merkle related to Betts, "For some time now we have been investigating possible applications of Lasers to weapon physics."[13] Kidder elaborated, "The principle objective of the laser research program is to ignite and burn a small amount of DT [deuterium and tritium] under controlled and reproducible laboratory conditions. The DT is to be brought to ignition conditions by means of an implosion at the focus of a high-power giant-pulse laser system. The blast and radioactivity produced by the thermonuclear explosion is to be fully and safely contained. Diagnostic instrumentation will be provided to observe the implosion, burn, and disassembly."[14] Kidder estimated a 100,000 joule laser would be necessary.

The early Q Division, unlike the CTR/magnetic mirror program, did not initially focus on building large machines. Instead it developed two separate technologies that the scientists hoped would eventually come together. Kidder and Q Division worked on high-power/short-pulse laser development and the more basic aspects of laser/plasma interaction. John Nuckolls in A Division worked on pellet designs and upgrading calculation methods. The early fusion program received about $1,000,000 a year in funding.

Q Division built its first prototype ruby laser in 1966. In 1970, Long Path, the first neodymium-glass laser system, came on-line. Difficulties in obtaining glass left the project with few amplifiers, so Long Path reflected the laser path back and forth nine times until it reached maximum output.

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[12] "Laser Fusion Article Approved by Ray Kidder for Publication in the Special Issue of NEWSLINE," 15 November 1973, LLNL Archives, 2. The article published differed substantially from the one quoted above and Kidder wrote a memo to that effect.
[13] T. C. Merkle to A. W. Betts, 23 October 1963, Box 170, Folder 1593, LLNL Archives.
[14] "Laser Fusion Article Approved by Ray Kidder for Publication in the Special Issue of NEWSLINE,"2.

Q Division performed thousands of target interaction experiments with Long Path. It remained active for five years.[15]

Other notable achievements of the early laser program included the development of a computer program, named WAZER, for laser implosion calculations, a multi-beam confocal laser irradiation system, selection and switch-out of single ultrashort laser pulses, invention of the e-beam controlled electric discharge carbon dioxide ($CO_2$) laser, an atomic iodine laser amplifier stabilized by an inhomogeneous magnetic field or a rare gas buffer, and the discovery of the emission of anomalously hard x-rays from laser produced plasmas.[16]

The A Division work on pellet design also grew out of the development of thermonuclear weapons. In the early thermonuclear weapon designs, a fission detonation was used to trigger the fusion detonation.[17] The fission physics package was known as the primary and the fusion package as the secondary in the thermonuclear weapon. As early as 1959, however, John Nuckolls speculated on the possibility of creating a fusion explosion for energy production without a fission primary. He posited that it was possible to compress a small amount of deuterium using a driver or non-nuclear repetitive primary. Early non-nuclear primaries included a charged particle accelerator, pulsed power source, or plasma/pellet gun. Nuckolls and A Division members immediately saw the implications of lasers for pellet research. Lasers could be used as non-nuclear drivers to implode capsules of deuterium.[18]

Although significant achievements in laser fusion research occurred from 1962 to 1969, the LLNL laser program was far from designing the kind of laser needed to produce enough energy (joules) for fusion. The laser program also suffered from fragmentation. In addition to Q and A Division, B Division (weapons) and the Electronics Engineering Division also became interested in laser research. B Division hoped to use lasers to carry information, "relaying data from ground zero of a nuclear test shot."[19] Electronics Engineering had a project to use lasers in the communications field.

[15] "Lasers: Advanced Technology for a Modern World," in LLNL, *Preparing for the 21st Century: 40 Years of Excellence,* UCRL-AR-108618 (Livermore: University of California, Department of Energy, 1992).
[16] "Laser Fusion Article Approved by Ray Kidder for Publication in the Special Issue of NEWSLINE," 3.
[17] The detonation of the primary provides energy to heat and compress the fuel in the secondary, causing fusion.
[18] J. H. Nuckolls, *Early Steps toward Inertial Fusion Energy 1952-1962,* 27 September 1999, UCRl-JC-131075, Livermore: Lawrence Livermore National Laboratory.
[19] "Versatile Lasers Shed Light on Plasma Studies," *The Magnet* (March 1966): 2.

In 1971, LLNL director Michael May asked physicist Carl Hausmann to reorganize the laser program and focus its efforts. Hausmann consolidated laser research efforts in Q, A, and B divisions into one laser effort which he re-named Y Division. However, it was the technical and theoretical advances made in the late 1960s that led to the dramatic increases in the laser program at LLNL. Nuckolls and a young physicist on Edward Teller's staff named Lowell Wood made some new significant computer calculations. "They suggested that by carefully time-tailoring the laser pulse, pellets could be ignited with a lot less laser energy than the 100,000 joules predicted by Kidder in 1961."[20]

**4. Development of ICF Lasers**

This prediction led to a progression of lasers developed in Y Division to test Wood and Nuckoll's theories. In 1975, Y Division developed the first ICF laser, Janus, with about 100 pounds of laser glass.[21] This two-beam laser demonstrated compression and thermonuclear burn for the first time. It was also used to learn more about plasma and thermonuclear physics and to help refine the LASNEX computer code used to make fusion predictions. The same year laser scientists developed the one-beam Cyclops which tested future optical designs for the next generation Shiva laser. Scientists used Cyclops for important target experiments as well. In 1976, the Argus laser came on line and was used to test laser/target interaction as well as other new technologies needed for the next generation of laser fusion systems. Each laser was more powerful than the last and built on the achievements of the one before it.

Building 174, a simple corrugated metal structure housed the early ICF lasers at LLNL. The 1970s saw a big increase in funding for ICF research. This was the result of several factors. An energy crisis in the early 1970s led to interest in research that might result in alternatives to fossil fuel. DOE increasingly allocated more money for ICF research nationally and LLNL's laser program looked promising. LLNL was named lead laboratory for ICF laser research. LLNL used this increased funding not only for bigger and more complex lasers but for more permanent laser facilities.

The next generation laser—Shiva—had been in the planning stages even during the development and experimentation with Janus. LLNL broke ground for a new laser facility (Building 391) in 1974 to house Shiva; it

[20] "Laser Fusion Article Approved by Ray Kidder for Publication in the Special Issue of NEWSLINE," 4.
[21] The early series of LLNL ICF lasers were given names of deities whose known features in common depictions reflected the laser's design. Thus, the two-faced Janus had two beams; one-eyed Cyclops had one beam; all-seeing, multi-eyed Argus had two beams; multi-armed Shiva had twenty beams. Nova and the National Ignition Facility did not continue the theme.

was near completion when Janus first fired. Breakthroughs in material and component research enabled the design of a laser with amplifier chains capable of four to eight times the energy output. Shiva was proposed as a twenty-arm laser with an output of 20 terawatts of energy. The Janus laser output was 0.2 terawatts and Cyclops output equaled 2 terawatts. Shiva was a huge leap in technology. Shiva was designed to irradiate a spherical target and was expected to demonstrate significant thermonuclear burn and breakeven. Breakeven meant that it took an equal amount of energy to achieve the output. The scale-up in laser design that Shiva entailed was the result of technological developments in high-power laser optics and propagation, laser diagnostics, optical stabilization and alignment, large-system maintenance, reliability engineering, and target chamber design.[22]

## 5. Building 391 and the Shiva and Nova Lasers

In addition to Shiva being a more powerful laser than any that came before it, Increment I of Building 391 was a state-of-the-art facility far more advanced than the basic metal structure that housed previous LLNL lasers. The facility had three components: a high-powered and well-controlled pulse laser (Shiva), a target-handling and irradiation chamber, and a diagnostics array. The building itself consisted of five major elements: a main laser bay, a target room, an energy-storage area, a single story laboratory element, and mechanical equipment areas. The building was 66,000 square feet. The laser bay, target room, and laboratory required stringent temperature and dust control. Essentially, most laser areas were state-of-the-art laminar-flow Class 1000 clean rooms, with an allowable 1 degree Fahrenheit (° F) variation in room temperature. The assembly room for laser components was a Class 100 clean room. Building 391 was a far cry from the metal structure that housed earlier lasers. Not just a shelter for the laser equipment it housed, the building itself can be seen as part of the laser design as its structure supported the mass of the beams and shielding, its layout reflected the beam's movement, and it had a self-conscious public face in terms of the lobby entrance and viewing areas.

Increment I of Building 391 was completed in 1976. The Shiva laser was complete and fired for the first time in November 1977. It achieved its goals on the first day it was fired. Shiva occupied as much space as a football field and was the most powerful laser of its time. The twenty beams could produce 10 kilojoules of energy in less than a billionth of a second. On May 18, 1978, the first full scale fusion experiment took place focusing 26 trillion watts of optical power for 95 trillionths of a second onto a microscopic size target. Also in 1978, Shiva staff began the implementation of a complete set of target diagnostics. Early in 1979 the

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[22] *Laser Program Annual Report 1975*, 7.

laser system drove DT fuel in the target pellets "to a density greater than lead, compressing the gaseous fusion fuel to between 50 to 100 times its normal liquid density." This was a significant milestone in ICF research.[23] The science and technology developed that made large laser systems like Shiva possible were "laser optimization theory, automatic laser alignment systems, digital controls, and extremely clean optomechnical assembly techniques."[24]

As early as 1976, LLNL had plans for the next generation laser—Shiva/Nova. Shiva would be upgraded and Nova added to it. Upgrading Shiva would increase its power tenfold. The goals of the Shiva/Nova laser were to demonstrate laser-driven thermonuclear fusion, achieve significant thermonuclear burn, achieve significant breakeven, and demonstrate the scientific feasibility of ICF. As with all of the lasers in the ICF program, experiments on Shiva/Nova would both advance fusion research and support the nuclear weapons program.

Advances in solid state lasers, such as new optical materials, laser glasses, and crystals, made these goals possible.[25] In particular, the development of fluorophosphate glass and improvements in the laser amplifier design led to the next generation gains.[26] Initially, Shiva/Nova was planned as a forty-armed laser with a spherical target in the middle. The Shiva/Nova plan required doubling the size of Building 391 to accommodate the additional twenty arms of the proposed Nova and Increment II of Building 391 was designed. Once Increment II and the new laser system were built, Shiva would be shut down and reconfigured.

By 1978, the designs of both Shiva/Nova and Increment II were modified. LLNL laser scientists redesigned Shiva/Nova to operate with only twenty arms, each followed by a 46 cm disk amplifier, and 74 cm focusing lens into the target. The change in design reflected easier maintenance and a more economical configuration. Increment II would house Nova (and is also referred to as the Nova addition). The project would now proceed in phases. Nova would be built first with ten beams (Phase I of Nova construction) and Shiva reconfigured into a ten-beam laser later (Phase II). At this point the Shiva/Nova language was dropped and replaced by references to the Phase I and Phase II of Nova.

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[23] Information and quote from "Shiva shutdown set for today," *The Laser Recap: The Laser Program Newsletter*, 23 December 1981, 6.
[24] *Laser Program Annual Report 1977*, 1-1.
[25] *Laser Program Annual Report 1976*, 1-3.
[26] *Laser Program Annual Report 1977*, 1-1.

Construction of Phase I began in 1979. Increment II included a laser bay located on the east side of the existing building (Increment I), a new target room in between the new and old laser bays, a master oscillator room, control room, clean room, laboratory space, and mechanical and equipment rooms. The addition added approximately 106,000 square feet to Building 391.

Building construction proceeded at the same time that laser components were being developed. Like the original Increment I Shiva building, the Increment II Nova addition was integral to the successful functioning of the laser. Building design was much more than mere housing for the machine but provided features that state-of-the-art lasers required to perform at peak levels.

The Nova laser focused an extreme concentration of energy onto a tiny target, which forced the deuterium and tritium to compress and create a microexplosion and an energy release. It worked in the following way: A small pulse of energy originated in the master oscillator, a device designed to create optical energy. It then split into ten separate pulses and was released through the Pockels cell, a shutter, into one of the 10 laser bay tubes. Each arm of the laser or tube was designed to amplify the pulse as it traveled towards the target. This was done by passing through 16 amplifiers (glass disks treated with neodymium atoms). Each amplifier had been energized by flashlamps, which added extra energy to the pulse as it traveled through the glass disk. There were also spatial filters, which protected the glass discs, mirrors, and lenses in the system. The spatial filter focused the beam through narrow pinholes, eradicating any incoherent light and passing it through a larger diameter to the next amplifier. The beam passed through a Faraday isolator, an optical one-way switch which prevented light from going backwards, and then through the harmonic converter. The harmonic converter was a special crystal, potassium dihydrogen phosphate (KDP) which converted infrared light to green or blue. (Green and blue photons have more energy than red ones.) The ten beams arrived simultaneously in the target chamber and ignited the target. All of this took only a millionth of a second.[27]

Nova required the improvement of laser components to prevent any diffusion of the light as it traveled through the beam. Non-coherent (non-focused) light damages mirrors, lenses and other components. The laser bay also had to be ultra-clean, cleaner than an operating room. Dust in a laser tube causes mini-explosions and damages components. LLNL partnered with industry to develop and improve laser technologies. Nova

[27] Drew Massey, *The Nova Comic Book* (Livermore: Lawrence Livermore National Laboratory), n.d.

required large lenses, mirrors, and specialized glass. It also required non-reflective coatings to prevent damage. Other specialized technologies included mechanical fabrication, high-energy pulsed power generation, and sophisticated electronic controls. A sampling of the technologies developed by LLNL in partnership with U.S. manufacturing firms appears in the following discussion. A comprehensive list of those companies that provided technology worth over $25,000 would include over 195 separate companies.

The Nova laser used over 100 mirrors and lenses ranging in size from 20 inches to 40 inches in diameter. The lenses were larger than any in previous optical systems and there was no existing process for volume production of high quality glass optics of this size. LLNL and two companies, Schott Glass Technologies of Pennsylvania and Hoya Optics of California, worked together to scale up existing technologies. These companies developed a process that was cheaper than previous techniques. Both companies expanded production facilities and now provide large quality optics to DOE, the Department of Defense (DoD), and international customers.[28] Schott Glass and LLNL also developed a new anti-reflection coating to prevent the 4 percent of light that was reflected back from each glass surface. The technique called neutral solution process actually chemically altered the surfaces of the finished glass elements. These altered pieces had the added benefit of having a high damage resistance.

Another major optical achievement was the development of a material for the focusing lenses of the laser which are located just after the crystals which transform infrared light to green or blue light before it hits the target chamber. Green and blue light turns regular glass brown. Fused silica (quartz) could be used for small lenses but when scaled up larger lenses had major impurities in them. Corning Glass Works of New York and Heraeus-Amerisil Inc. of New Jersey substantially improved the chemical purity and atmospheric controls required to produce large quartz lenses and provided LLNL with the technology needed for focusing lenses. Westinghouse provided the best anti-reflective coating for the quartz focusing lens.

The last stage of the laser beam before it reached the target chamber was the conversion of infrared light to green or blue light. This gave the beam added energy before it hit the target. This occurred by a process called harmonic conversion in which the light passes through a KDP crystal.

[28] Information on this and all other new technologies developed by LLNL and industry from *The Nova Laser Project: Its Contributions to U.S. Industrial Capabilities* (Livermore: Lawrence Livermore National Laboratory, n.d.).

Crystals are produced quite differently than glass lenses, which are made through a high temperature melting process. Crystals are grown in a temperature-controlled chemical bath over long periods of time. The largest crystals ever grown before Nova were 2 inches square whereas the beam of Nova would be 2.5 feet in diameter when it reached the crystal. Cleveland Crystals of Ohio and Interactive Radiation of New Jersey worked with LLNL to develop a system that would accommodate the larger beam of Nova. They designed a mosaic array of crystals—three by three squares of 10-inch crystals (Fig. 16). The two companies created an aggressive research and development program that grew 400-pound crystal boules in nine to eleven months.[29] LLNL developed a precision diamond lathe that could machine crystal surfaces to high optical qualities. They transferred this technical knowledge to fourteen companies.

LLNL also developed improved technology in the mechanical and energy sub-systems of the Nova laser. LLNL developed an improved laser oscillator to produce reliable and repeatable infrared laser pulses. Commercially available oscillators were not adequate for the job. LLNL developed an oscillator that became the most stable and reliable in the world. It combined very high speed switches with sophisticated electronic feedback systems. LLNL and General Electric (GE), Maxwell, and Aerovox improved the storage of high voltage capacitors, the energy source that powers Nova, by a factor of four at one-third of the cost. This is now an international standard. LLNL also developed minimum-distortion welding techniques to use while constructing the spaceframe and other subassemblies. This welding technique minimized distortion and prevented the re-machining of the frame. LLNL also developed high-pressure Freon surface cleaning techniques to remove dust from amplifiers. This technique was transferred to over 25 aerospace, optics, and engineering firms.

The Nova laser facility took over eight years to complete. The construction of Increment II of Building 391 was completed in 1983, with the laser components assembled and in place in December 1984. The first full scale shot of all ten laser beams concentrated on the target took place on December 19, 1984. Four months later final construction and activation took place and a dedication ceremony marked the event. The Nova laser was ten times more powerful than Shiva had been. The ten-armed Nova could produce 100 trillion watts of infrared laser power for a billionth of a second. For that brief moment Nova produced more power than all the combined electrical generating plants in the United States.

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[29] A boule is a single crystal ingot grown by synthetic means.

The funding for Phase II of the Nova project never materialized and Shiva was never reconfigured; Nova's design remained at ten arms. The Shiva laser was deactivated in December 1981. To fill the gap before the Nova laser would be functional, the LLNL ICF program built Novette. Novette, which came on line in 1983, functioned as a prototype for Nova and a target experimentation facility. It was built and installed in Building 381. It was the first large multikilojoule laser designed to use both infrared and ultra-violet and green light. In July of 1984, Novette created the first soft-x-ray laser in the laboratory.[30] Novette shut down in August 1984 and its two beams were moved to Building 391 to complete the Nova project.

With Increment II completed and Nova installed, the Increment I (original) portion of Building 391 had no laser in its laser bay. In 1984, LLNL began planning to install an additional target chamber in the former Shiva laser bay and extend two of Nova's ten arms into it (Fig. 23). The resulting two-beam configuration and target chamber was known as the Two-Beam. The Two-Beam doubled the rate at which target experiments could be performed. In its final form, Nova consisted of the Phase I ten-armed laser and an extension of two of those arms into a second target chamber located in the original Shiva laser bay (Fig. 4 and 5). The Two-Beam was completed in July 1985.

By 1986, Nova was fully operational. It was the largest laser in the world at the time and many firsts in ICF laser fusion were achieved on it. In January 1986, Nova produced the largest laser fusion yield of 11 trillion neutrons. In August 1987, Nova compressed a target to 1/30$^{th}$ of its original size—almost the goal needed to reach high gain (amplification). In December 1988, all Nova laser disks were replaced with improved disks. Since Nova's first operation, platinum particulates in the laser glass made peak performance elusive. The new platinum-free glass rectified this situation.[31] In April 1989 Nova exceeded all performance predictions, generating over 120 kilojoules of energy at the infrared wavelength for 2.5 nanoseconds.[32]

### 6. Beamlet Demonstration Project

As early as 1988, LLNL began to develop plans for an upgraded Nova. A joint LLNL-LANL program called Halite-Centurian conducted underground tests at the Nevada Test Site that, coupled with Nova test results, demonstrated the need for a much more powerful laser to reach ignition. In 1990, LLNL proposed a Nova Upgrade that would consist of

[30] Laser Programs Document Services, *Laser Programs: The First 25 Years…1972-1997,*UCRL-TB-128043 (Livermore: Lawrence Livermore National Laboratory, n.d.), 5.
[31] "The Nova Laser," *Energy and Technology Review,* July/August 1989, 26.
[32] *Laser Programs,* 5.

an 18-beamline, high-power, neodymium-doped glass laser that would be much more compact and efficient. The upgraded Nova would have only one amplifier instead of five. Each beamline would accommodate 16 optically-independent laser "beamlets."[33] In 1991, LLNL established the Beamlet Demonstration Project and began development of the next generation technology for ICF lasers. Beamlet was built in Building 381. Beamlet technology did not result in the Nova Upgrade but instead resulted in a proto-type beamline for a much bigger and more powerful laser system called the National Ignition Facility (NIF). The NIF would be a DOE center to study ICF and high energy density science in lieu of underground nuclear testing. The NIF laser would have 192 beams and would produce 1.8 million joules of energy. Design began in 1996 and construction in 1997. Beamlet was dismantled in 1998 and transferred to Sandia National Laboratories (SNL). The NIF is currently under construction.[34]

### 7. Petawatt Advanced Fusion Project

In the 1990s, the addition of a Petawatt chamber and short-pulse beam gave Nova added power through a different means. In 1992, the Petawatt Advanced Fusion Project began to explore a high-risk but potentially big leap in ICF technology. The petawatt (peta = quadrillion) laser was designed and developed to test a new "fast ignition" approach to ICF. The Petawatt laser was a hybrid of a titanium-doped sapphire (Ti:sapphire) laser and neodymium glass amplifiers. It worked by creating a very short pulse that was stretched in time in a separate master oscillator room, injecting it into one of Nova's beamlines where it was amplified, compressing the pulse in a large vacuum vessel next to the Nova target chamber, and focusing the pulse onto targets in a special new target chamber (Fig. 22 and Photo 35). The Petawatt laser required technological advancements in optical materials, short-pulse laser technology, and diffraction grating technology. The modifications to Nova needed to support the Petawatt implementation presented significant engineering challenges. Substantial changes to the Nova laser bay, target bay, and control system were developed over a four year period and implemented without disrupting the Nova firing schedule. A series of shots began in 1995 that tested the new Petawatt configuration and the final full test in May 1996 produced a world record 1.25 petawatts of power—a full 25

[33] W. H. Lodermilk, et.al., *The Nova Upgrade Facility,* UCRL-JC-105734 (Livermore: Lawrence Livermore National Laboratory, 1991).
[34] *Laser Programs,* 6-7.

percent more than expected and ten times the peak power of the Nova laser.[35]

LLNL fired the Nova laser for the last time in May 1999. It had performed over 14,000 experiments. Most experiments were designed to advance fusion research, although approximately 30 percent of its tests were in support of the nuclear weapons program.

After 1999, several rooms in Building 391 were refurbished to house a variety of support programs for the NIF program, including flash lamp inspection and testing, power conditioning system prototype module testing, amplifier testing, capacitor testing, optics processing, KDP crystal processing, analytical X-ray laboratory, and various other laser research (Photo 17 and 26).

[35] "Crossing the Petawatt Threshold," *Science and Technology Review*, December 1996; and Gregory Tietbohl, et al., *Engineering the Petawatt Laser Into Nova*, UCRL-JC-127749 (Livermore: Lawrence Livermore National Laboratory, 1997).

## Part II. ARCHITECTURAL INFORMATION

### A. General Statement:

1. **Architectural character:** The Nova building (Building 391) is constructed of concrete with high bays along the central east-west core of the building. One-story sections run along the north and south sides of the core. Built in two increments (Increment I on the west and Increment II on the east), the building was constructed specifically to house large laser systems—initially the Shiva laser (Increment I) and then Nova (Increment II). It is an industrial building. Although there is no standard laser building type—lasers are found in a variety of different industrial buildings—it is clear that the large laser systems housed in Building 391 influenced the basic design of the building. Like other industrial buildings, this laser building was designed to support and accommodate the machines it housed. This is particularly evident in the high bays, with their clean room flooring and ceiling, in the fact that the Nova laser bay (the building's east high bay) has a floor supported independently of the building's other structural support, and in the design of the target chamber room, which was built to surround, support, and shield the target chamber.

2. **Condition of fabric:** The current condition of the Nova building is good. The building is in active use and is maintained by LLNL's plant engineering organization. Although the Nova laser system itself is partially disassembled, the building retains structural and historical integrity.

### B. Description of Exterior:

1. **Overall dimensions:** Increment I was a rectangle with the north and south sides longer than the east and west. The basic design was a 160 foot by 52 foot rectangular laser bay (a high bay rising to 47 feet 5 inches above ground level) for the Shiva laser with a separate 68 foot by 68 foot high bay target room (at a height of 62 feet) in the core of the building; one-story offices and support fabrication laboratories ran along the south side and mechanical support rooms along the north side; a fan room and vestibule extended to the west. The building had a basement. Increment II, the Nova addition, was similarly rectangular, extending the building 360 feet to the east. Similar in concept to the original building, the addition had a 220 foot by 58 foot 5 inches rectangular laser bay at a height of 47 feet 5 inches for the Nova laser at its core, with labs and offices on the south side and mechanical support on the north side. Unlike Increment I, however, the Nova addition did not have its target chamber room immediately extending from the laser bay. Instead, the Nova laser beams were directed west into a 59 foot by 106 foot 2 inches switchyard (62 feet high) where turning mirrors then sent them to the target chamber in the

100 foot by 60 foot target chamber room (which rises from the basement to 62 feet above ground level) to the north of the switchyard. The addition also extended the building's basement approximately 332 feet to the east.

The resulting building is approximately 600 feet long by 210 feet wide (at its widest point; it is 154 feet wide at the west end, 209 feet 11 inches wide at the center, and 169 feet 1-3/8 inches wide at the east end).

2. **Foundations:** The foundation is reinforced concrete. It is poured in 8 inch slabs in the addition. The Nova laser bay on the first floor also has a concrete slab floor that rests on steel beams extending through the basement level.

3. **Walls:** The building's exterior wall design includes both concrete and metal surfaces (Photo 5 and 7). The high bay in the Increment I (west) portion of the building has a sandblast concrete finish. The central high bays of the switchyard and target chamber room also have a sandblast concrete finish with a smooth concrete finish in a band along the top. The two-story diagnostics-and-shop area north of the target chamber room is covered in insulated metal siding (Photo 4). The Nova laser bay in Increment II is concrete clad in insulated metal siding (Photo 3). The north side of Increment II is insulated metal siding, as is the north side of Increment I. On the south side, the one-story office-and-laboratories area to the south of the Nova laser bay is insulated metal siding (Photo 1), while the one-story laboratories area to the south of the original Shiva laser bay is constructed of tilt-up concrete panels (Photo 8). The central section of the south side is clad in insulated metal siding.

4. **Structural system, framing:** This is a steel-framed building. The Nova high bay has a concrete slab floor that rests on steel beams extending through the basement level, keeping the support for the high bay separate from the rest of the building to reduce the impact of vibrations and other movement on the Nova laser system. The Nova laser components within the high bay are placed on a spaceframe welded out of 4 inch by 4 inch steel beams (Photo 31). The spaceframe was assembled to close tolerances, keeping the components it holds level and assisting with the alignment of the laser beam. The Nova target chamber also rested on a spaceframe welded out of 6 inch by 6 inch steel beams. The spaceframe rises from the basement level, holding the cradle for the target chamber at the first floor level and extending up to hold the turning mirrors that direct the beam into the target chamber and allowing technicians to access the beamline (Photo 19 and 35).

5. **Porches, stoops, balconies, porticoes, bulkheads**: There are none. The original lobby entrance is a set of glass doors; the lobby's shed roof extends slightly to form a slight awning (Photo 9).

6. **Chimneys:** There are no chimneys.

7. **Openings:**
    a. **Doorways and doors:**
        1. **Pedestrian doors:** Building 391 offers multiple pedestrian entrances. The primary pedestrian doors are located on the building's south side, entering the original lobby (Room 1160) and the Nova lobby (Room 1230). These areas are each accessed by two-leaf glass doors (Photo 12). The laser labs along the east portion of the south side are accessed by double metal doors (Photo 2), as are the labs along the west portion of the south side (Photo 8). The mechanical rooms and other support areas on the building's east end, west end, and north side have both one- and two-leaf pedestrian doors.

        2. **Roll-up doors:** There are a series of metal roll-up doors providing equipment access on the north side of the basement level (Photo 27). There are similar metal roll-up doors on the buildings east and west ends (Photo 3 and 6).

    b. **Windows and shutters:** There are no windows on the building's north side, although there are fixed metal louvers for ventilation. Similarly, the building's east and west sides have fixed metal louvers. The building's windows are on the south side. The original lobby area (Room 1160) has windows as its exterior (south) wall. These are seven aluminum-sash single-light windows about 6.5 feet tall, each above a single-light 1.5 foot tall window (Photo 10). One set of windows sits to the west and six to the east of the glass entry doors (Photo 9).

        The exterior (south) wall of the offices to the east of the original lobby is also formed of windows. There are five 12-light, aluminum sash windows approximately 20 feet tall.

        The exterior (south) wall of the Nova lobby (Room 1230) has two-leaf glass doors with three one-light, 10 foot tall metal sash windows—one to the west and two to the east of the doors. There is a single-light window above the two-leaf glass doors to match the height of the windows on either side (Photo 12).

8. **Roof:** The roofs of the building's high bays are flat. They are built-up roofing on rigid insulation on metal decking on the Nova laser bay, built-up roof on rigid insulation on concrete deck above the switchyard and the Nova target chamber room, and built-up roof on the former Shiva laser bay. The roof is also flat and of built-up roofing on rigid insulation on metal decking above the light labs on the east and west portions of the building's south side. The central portion of the south side has a prefabricated metal shed roof on both its one-story and two-story sections. The roof of the mechanical rooms, diagnostic areas, and fan loft on the north side of the building is a shed roof of preformed metal roof on metal rafters.

**C. Description of Interior:**

1. **Floor plans:** Current floor plans are shown in Figures 1, 2, and 3.

   The Building 391 floor plan is most easily understood as three sections: west, central, and east. An east-west hallway runs through the south portion of each section, connecting the offices and labs on that side of the building. The west section contains the 1100-series room numbers on the first floor (the B100-series room numbers in the basement). The central section includes the 1200-series room numbers on the first floor (the B200-series room numbers in the basement). The east section contains the 1300-series room numbers on the first floor (the B300-series room numbers in the basement).

   The west section is the original Increment I with the former Shiva high bay (Room 1110, now a large clean room for laser component research and manufacturing) and part of the former Shiva target room, which became the Nova Two-Beam room during Nova's tenure, and is now the Amplifier Manufacturing/Assembly Area (AMPLAB) (Room B120, which is a high bay extending up through the first floor). The west section also holds the original building lobby (Room 1160). The viewing gallery that originally overlooked Shiva is accessible from the original lobby and the lobby's ceiling rises from one-story on the external (south) wall to the top of the two-story viewing gallery area. Small labs and offices run along the one-story hallway on the south side of the west section.

   The central and east sections are Increment II. The central section holds the Nova target chamber room (Room B225), which extends up through the first floor to the high bay roof. It also contains the Nova switchyard (Room 1250) and the Nova Master Oscillator Room (MOR). This section of the building has the Nova lobby (Room 1230), which is now used as the building's main lobby entrance. The lobby sits to the south of the entrance to the Nova laser bay. It is part of the one-story series of offices and laboratories that extend along the building's south side; a series of offices extend east from the lobby to the original lobby along the south side's hallway.

The east section houses the Nova laser bay (Room 1340), its control room (Room 1302A) and the visitors viewing gallery (Room 1310). The room to the east and south of the control room contain laser systems and laboratories.

2. **Stairways:** Four half-turn stairways extend between the first floor and the basement on the south side of the building and one at the building's west end. A half-turn stairway reaches from the old lobby (Room 1160) to the corridor to the second-floor viewing areas. On the building's south side, there is one half-turn stairway between the basement and the first floor. There is also a steel half-turn stairway with a short half-turn stair flight at the bottom between the basement level (Room B235) and the diagnostics room (Room 1235) north of the target chamber room (Photo 22). A straight flight of stairs runs from the diagnostic room level to the top of that room. The steel spaceframe holding the target chamber in the target chamber room (Room B225) has stairs between the basement and first floor levels; stairs also extend into the upper reaches of the spaceframe, allowing access to the individual beamlines entering the target chamber room and target chamber (Photo 19).

3. **Flooring:**
    a. **Basement:** There are concrete floors in the hallways and most room spaces, including the target chamber room (Room B225) and the capacitor room (Room B350) (Photo 21 and 25). Vinyl tile covers the concrete in the corridor floors (Photo 23). The AMPLAB (Room B120) has raised access flooring above concrete; the access flooring is clean room tile, in solid and perforated panels for air flow (Photo 17).
    b. **First Floor:**
        1. West section: The corridors and original lobby (Room 1160) are carpeted in low-pile industrial carpeting (Photo 11). The rooms are primarily clean rooms, with access flooring of 24 inches by 24 inches solid and perforated panels for air flow.
        2. Central section: The Nova lobby (Room 1230) and the hallway extending to the west are carpeted in low-pile industrial carpeting (Photo 11 and 13). The switchyard (Room 1250) has access flooring 3 feet above a concrete floor (Photo 38). The access flooring is 24 inches by 24

inches solid and perforated panels supporting the clean room air flow of the space.

3. East section: The Nova laser bay (Room 1340) has access flooring 4 feet above a concrete floor (Photo 31). The access flooring is 24 inches by 24 inches solid and perforated panels supporting the clean room air floor of the space. The lab and viewing area floors along the south side of the Nova laser bay are covered in vinyl floor tiles. The corridor similarly is covered in large vinyl floor tiles (Photo 28). The control room (Room 1302A) and war room (Room 1302, which housed Nova's technicians) floors are covered in low-pile, blue, industrial carpeting (Photo 29).

**c. Second Floor:** The corridor to the second-floor viewing areas is carpeted.

4. **Wall and ceiling finish:** The clean room spaces, including the AMPLAB (Room B120), laser component research and manufacturing areas (Rooms 1110, 1120), switchyard (Room 1250), and Nova laser bay (Room 1340) have integrated ceilings with a plenum for air handling.

   **a. Basement:** The exterior basement walls and several of the interior walls are concrete. Interior office and manufacturing area labs are gypsum board. The clean room enclosures (Rooms B350A and B350B) now sitting in the former Nova capacitor bank area (Room B350) are heavy plastic on a wood frame (Photo 24). The target chamber room (Room B225) has 6 foot-thick concrete walls.

   **b. First Floor:** The ceilings of the offices and other non-clean room areas are acoustic tile; the original lobby (Room 1160) is gypsum board.

   1. West section: The walls of the former Shiva laser high bay and target chamber are concrete covered in gypsum board (Photo 18). The interior walls of the corridors and laboratories are gypsum board. The original lobby (Room 1160) is gypsum board, a laminated wood slat wall covering has been added on some areas of the walls. The room currently is divided into office space by fabric cubicle panels (Photo 15).

   2. Central Section: The corridor walls are gypsum board with laminated wood slat wall covering the north side of the hall (Photo 11). The office walls are gypsum board; rooms are further divided into offices by fabric cubicle panels (Photo

14). The lobby (Room 1230) is gypsum board; the west wall is covered laminated wood slat wall covering. The walls of the switchyard are concrete; the wall between the switchyard and Nova laser bay is 24.5 inches thick with perforations for beamlines and doors (Photo 38). The wall between the switchyard and target chamber room is perforated for the beamlines (Photo 39).

3. East section: The walls of the portion of the corridor extending from the lobby (Room 123) past the war room (Room 1302), control room (Room 1302A), and viewing gallery (Room 1310) are covered in the original low-pile, brown carpeting (Photo 28). The wall between the control room (Room 1302A) and the corridor is glass (Photo 28). The interior walls of the offices and smaller laser labs extending to the east end of the building are gypsum board. The Nova laser bay walls are concrete with gypsum board facing (Photo 30 and Fig. 26).

**c. Second Floo**r: The wall of the corridor to the second-floor viewing area is textured concrete (Photo 15).

**5. Openings:**

**a. Doorways and doors:** There are both wood and metal doors providing pedestrian access to offices and labs throughout the building.

The doors to the Nova laser target chamber (Room B225) are shielding doors installed for use in the event that Nova achieved sustained fusion. The basement-level door out of the target chamber room into the basement's interior (Corridor 5) was designed as a shielding door and the concrete wall of the corridor is designed to fit the stair step design of the door's seal (Photo 20 and Fig. 24 and 27). The door between the target chamber room (B225) and the support area to the north (Room B235) has never been closed; it is a 70 inch thick, two-door shielding closure; the two doors are designed to interlock when closed (Photo 21 and 22 and Fig. 25 and 28). The north (exterior) sides of the doors have a protruding lower portion that is currently used as workbench/shelf storage. On the first floor, the door between the switchyard (Room 1250) and the target chamber room is metal on the switchyard (Photo 36 and 37) (south) side and a thick shielding door on the target chamber room (north) side (Fig. 27).

There is a metal roll-up door as well as a pedestrian door between the Nova laser bay and the switchyard (Photo 38).

**Windows:** There are a few internal windows in the east section of the building. There is single-light, metal-framed, fixed sash window between the Nova lobby (Room 1230) and the war room (Room 1302) and an identical one between the war room and the control room (Room 1302). There is also a sliding window on the south wall of the war room, allowing personnel to communicate from the hallway (Corridor 5).

The viewing room (Room 1310) looking at the Nova laser bay has a set of windows forming a bay that extends into the laser bay. There are sixteen 16 inches by 48 inches single-light, metal sash windows on the front, six 16 inches by 48 inches single-light, metal sash windows along the top, and a triangular sash at the top of each side (Photo 32). The windows are formed of two panes of glass with a liquid containing copper and sulfur in between, to absorb light. Visitors could be in the viewing room during alignment of the laser beams.

6. **Decorative features and trim:** There are no decorative architectural features on the building. The mural in the original control room provides the only deliberately decorative detail within the building. Its abstract, energetic design of beamlines and target reflects both the graphic design sensibility of the period (the early 1980s) and the optimistic, high-tech vision of Nova (Fig. 20). The mural is largely obscured currently by the office partitions in Room 1302A (Photo 29).

   The design of the technology and the supporting infrastructure within the building does give the laser bays and switchyard a particularly "high-tech" appearance. In the early years of the LLNL laser program, blue was chosen as the color of the component housings and was used consistently on all of LLNL's lasers beginning with Janus. At LLNL, the color is known as "laser blue." The laser program also chose white for the steel spaceframes and matte black for the supports. The blue combines with the stark white of the clean room floors and ceilings, the interior laser bay walls, and the steel spaceframes to create a very clean, crisp feeling.

   Although the building has a basic industrial design, it was part of the overall move of LLNL's laser activities into a larger, more visible arena within the site. Building 391 sits at the northwest corner of the laser area, an attractively designed set of buildings around a large lawn area, offering a campus-like environment for the research undertaken there. The building also has a spacious original lobby (Room 1160) and a viewing room (Room 1310) for visitors on the south side of the Nova laser bay and viewing platforms/galleries on the second-floor level that look down on the former Shiva laser bay and Nova switchyard. These features, while not architecturally decorative, reflect the laser program's awareness of the broader interest in and the significance of the research undertaken in the building.

7. **Hardware:** There is no historic hardware.

8. **Mechanical Equipment:**
    a. **Heating, air conditioning, ventilation**: All heating, air conditioning and ventilation for the building is housed in the basement. A power substation adjacent to the equipment room provides all power requirements for operation.[36] Utilities extend through the building via conduits and pipes along the basement ceiling (Photo 16).

       The original Shiva laser bay (Room 1110) was a clean room with vertical laminar air flow from high efficiency particulate (HEPA) filters in the ceiling to a perforated raised floor that created a return air plenum in the space below. The Shiva target room (Room B120) had identical environmental controls to the laser bay. Both rooms have been renovated and upgraded; they are clean rooms used for NIF component support (Photo 17).

       The Nova laser bay was designed as a class 10,000 clean room with vertical laminar flow, HEPA filters, and temperature control.

    b. **Lighting:** There are no historically significant lighting fixtures. Fluorescent lighting is used throughout the building.

    c. **Plumbing:** There are no historically significant plumbing fixtures. Water is supplied via LLNL's infrastructure.

    d. **Cranes:** There are two cranes in the Nova laser bay, one stationed at each end of the room.

9. **Original Furnishings:** There is no historic furniture. In terms of historic equipment, Shiva is gone; Nova is described below.

[36] *Laser Program Annual Report 1976*, 1-6 – 1-7.

10. **Description of Machine:** Nova was a ten-beam, solid-state laser made with neodymium-doped phosphate laser glass. It also included a Petawatt laser of titanium-doped sapphire (Ti:sapphire). There were over 400 major component assemblies weighing over 2000 pounds. These components were mounted on a spaceframe made of ten miles of structural steel. The laser machine was housed in four separate rooms, each a clean room fitted with a spaceframe. The rooms housed the following component systems: master oscillator, laser, diagnostics and mirrors, and additional mirrors and target chamber (Fig. 8). Additional rooms housed support systems, including power generation, mechanical equipment, diagnostics, and controls.[37]

    a. **Spaceframe:** The spaceframe was made of square hollow steel tubing and designed to provide support for the laser components (Photo 33 and 34). There were three main sections of it—two that held amplifier components (in the Nova laser bay, Room 1340) (Photo 30, 34, and 41 and Fig. 6) and one that held the turning mirrors and target chamber (Room B225) (Fig. 7 and 9 and Photo 19 and 40). The spaceframe was built in Oakland, California, in 50 pre-fabricated sections and reassembled on site. The frame had to meet tolerances within 3 mm. Some sections when welded had tolerances as large as 6 mm. This was remedied by using shim plates and component cradle adjustments. The spaceframe held the laser still and protected it from vibration. This was accomplished by roller bearing supports that allowed the frame to expand and return to its position when the air temperature changed. A temperature-controlled environment also limited thermal expansion.

    b. **Master Oscillator:** The master oscillator was an independent laser subsystem that provided the initial pulse, gain variation, temporal and spatial shaping, and prepulse discrimination to the entire Nova system. The master oscillator consisted of a series of short pulse oscillators, amplifiers, Pockels cells, and spatial filters (Fig. 10). The master oscillator room was located in the basement on the east wall of the target room. It housed the master oscillator and pulse conditioning system. Half of the room was a screen room, which provided shielding from radio-frequency for the oscillator. It was temperature controlled and had HEPA filters. The master oscillator room also contained an array splitter. The array splitter consisted of lenses that split the original pulse into ten discreet pulses. The pulses then traveled

[37] Descriptions of the machine parts and components from W. W. Simmons and R. O. Godwin, *Nova Laser Fusion Facility: Design, Engineering and Assembly Overview* (Livermore: Lawrence Livermore National Laboratory, 1983).

through a Pockels cell, which released the coherent light into the beamline. The Pockels cell was a crystal placed between crossed polarizers; it acted as a fast optical gate preventing interchain oscillations and reducing unwanted amplified spontaneous emissions.[38]

**c. Beamlines:** The Nova laser had ten beamlines that ran from outside the master oscillator room to the last set of mirrors in the target bay before the beam entered the target chamber (Photo 42). The beamlines were 36-inch diameter aluminum tubes to encase the laser beam (Fig. 11). The beamlines were a non-sealed system. Designers initially planned the beamlines to be sealed and filled with nitrogen to prevent air disturbance but prototype beamlines used for Novette demonstrated that the beamline alone would be adequate protection for the laser beam. The system also had many panels and weldments to cover the switchyard mirror towers and target bay mirror housings. There was also an additional tower in the switchyard for supporting the tubes.

**d. Spatial filters:** The spatial filters were stainless steel vacuum tubes sealed at both ends by lenses (Fig. 12 and 15). They enlarged and smoothed the shape of the laser beam. They were interspersed throughout both the master oscillator and the beamlines between amplifiers. In each spatial filter the beam was focused through a pinhole, and then expanded and re-collimated. The small opening eradicated non-coherent or focused light. There were 80 spatial filters on Nova that ranged in size from 5 cm to 74 cm apertures. The largest was 24 m long. There were ten in the master oscillator and seven in each of the beamlines.

**e. Amplifiers:** The amplifiers were the heart of the laser, increasing the power of the beam as it traveled through them. There were 166 amplifiers, ranging in size from 5 cm to 46 cm. Six amplifiers were in the master oscillator room used for the splitting and preamplification process. Each beamline held sixteen additional amplifiers, each a little bigger than the last. The amplifiers were made of neodymium-doped glass and had highly reflective surfaces, a minimum pump volume, no light traps, and a minimum of energy absorbing metal (Fig. 13 and 15). The amplifiers were surrounded by flash lamps, which

[38] E. Victor George, ed., *The Laser Program Annual Report, 1981* (Livermore: Lawrence Livermore National Laboratory, 1982).

excited the neodymium increasing the light as it passed through them.

f. **Faraday rotator isolator:** The Faraday rotator (FR) isolator was an electro-optical device that protected beam optics from back reflections and oscillations between amplifier stages (Photo 33 and Fig. 14 and 15). It consisted of an FR-5 terbium-doped rotator disk, a solenoid coil that surrounded the rotator, and polarizer end plates twisted about the optic axis. Nova had 42 Faraday rotators—two 5 cm aperture rotators and ten each of the 9.4 cm, 15 cm, 20.8 cm, and 31.5 cm aperture rotators. Many of the rotators came from the previous Shiva laser with slight modifications.

g. **Potassium Dihydrogen Phosphate (KDP) crystal array:** The KDP crystal array converted the frequency of optical radiation from infrared to blue or green light. KDP was grown in a water solution to 400 lb. crystal boules. The boules were then cut into 25.4 cm square crystals, highly polished, and set into a 3 by 3 array whose total aperture was 77 cm (Fig. 16). The crystals were sandwiched between transparent layers of fused silica.

h. **Turning mirrors:** Turning mirrors directed the laser beams 180 feet from the end of the beamlines to the target chamber (Photo 39 and 40). Nine of the beams used four mirrors and one beam used six mirrors. Mirror mounts had a three-legged gimbal to tilt for accurate adjustment (Fig. 17). There were four different sizes of mounts (one with two different bezel sizes) to accommodate the five different mirror sizes in the Nova laser.

i. **Target chamber:** Built by Chicago Bridge and Iron Company, the target chamber consisted of three sections: a central structural ring and two hemispherical heads (Fig. 9). The chamber was built of aluminum alloy, which has a short recovery period from radiation following a shot. Its inside diameter was 4.6 m; it was 12.7 cm thick and weighed about 20 tons. The outside walls had a circumference of 2.3 m. The central ring supported the target positioner, viewing optics, vacuum pumps, and target diagnostics. The two hemispheres supported lens positioners, handling equipment, and target diagnostics (Fig. 18). There were over 150 ports for target diagnostics. The target chamber rested in a steel mounting cradle (Photo 35). The ten beamlines entered through openings around the chamber, no two directly opposite each other (Photo 43).

j. **Power systems/Energy Storage:** The Nova laser required energy to power the 1,600 high-power circuits which drove the 4,400 flashlamps and 32 Faraday rotators. 15020 million volt amps (MVA) of peak AC power was drawn from the 13.8 kilovolt (kV) three-phase lines to charge the capacitors in 30 seconds. The capacitor bank provided over 100 megajoules (MJ) of energy and was housed in sixteen rows, each 53 feet long, comprised of steel shelving and circuits stacked eight units high on each side of the aisle (Fig. 19). The energy storage room (Room B350) was in the basement directly underneath the Nova laser bay. The space was air conditioned to prolong capacitor life. Electrical power came from a substation located outside at basement level

k. **Control/Diagnostics:** The Nova laser relied on an extensive, sophisticated computer control network which handled multiple tasks including: laser alignment, target alignment, capacitor-bank charge and fire sequencing, and laser and target diagnostic data processing. The computer system was comprised of three Digital Equipment Corporation (DEC) VAX-11780 mini-computers and 50 LSI-11/23 micro-computers (Fig. 20 and 21). Real-time operation of the laser was performed by the Power Conditioning Control System, which synchronized all active laser components (amplifiers, isolators, shutters) with the master oscillator/pulse-generator and monitored laser and pulsed power segments during the firing sequence.

l. **Petawatt Chamber:** The Petawatt laser system included a Ti:sapphire/neodymium-doped glass (Nd:glass) master oscillator that used one of the Nova beamlines to amplify a stretched pulsed, then compressed the pulse before focusing it onto the target, which greatly increased the beam power. The Petawatt components were quite large and difficult to install within the already existing Nova laser. Large system components included: diffraction gratings and mirrors, vacuum compressor chamber, target chamber, and parabolic focusing mirror. Other system components included: an injection beamline, transport spatial filters, laser diagnostics, alignment components, motor controls, interlocks, timing and synchronization systems, support structures and vacuum systems. The Petawatt laser system had its own master oscillator. The compression chamber and target chamber were installed within the Nova target chamber room (Photo 35 and Fig. 22).

**D. Site:** Since the early 1970s, LLNL has allocated the north-central portion of the Livermore site to its laser program and new construction for the program has taken place there. The laser buildings are arranged in three groupings around a large grassy area between the North Inner Loop and North Outer Loop roads, forming a focused, pleasant, campus-like environment. The newer, NIF construction is to the east of this main grouping, while Building 391 forms the northwest portion of it.

1. **Historic landscape design:** Building 391 does not have a historic landscape design. There are trees on the grounds to the south of the building and the walkways and lawns of the larger laser area extend to the southeast. The ground on the north side of the building slopes down from both east and west, allowing the basement level of the central portion of the building to be at ground level.

2. **Outbuildings:** The Nova building's outbuildings consist of prefabricated storage buildings, support trailers for contractors, and Sea-Land Containers stacked and used as storage buildings. These structures lie to the north of Building 391; they have no historic significance.

## Part III. SOURCES OF INFORMATION

**A. Architectural Drawings:** Architectural drawings are held in the Lawrence Livermore National Laboratory Plant Engineering Library.

"High Energy Laser Building 391, Vicinity Site Map, Site Plan," PLZ74-391-001JA

"High Energy Laser Building 391, North and South Elevations," PLZ74-391-034JA

"High Energy Laser Building 391, East and West Elevations," PLZ74-391-035JA

"High Energy Laser Building 391, First Floor Plan," PLZ74-391-027JA

"High Energy Laser Building 391, Basement Floor Plan," PLZ74-391-026JA

"High Energy Laser Building 391, Gallery Floor Plan and High Bay Reflected Ceiling Plan," PLZ74-391-028JA

"High Energy Laser Building 391, Basement and Low Bay Reflected Ceiling Plan," PLZ74-391-029JA

"Shiva Nova Addition, Shiva Nova Office Building, Site Plan," PLA77-391-006C

"Nova Laser Facility, Site Plan and Details," PLZ78-391-065JB

"Nova Laser Facility, Lower Level Floor Plan West Part," PLZ78-391-066JZ

"Nova Laser Facility, Lower Level Floor Plan East Part," PLZ78-391-067JF

"Nova Laser Facility, First Floor Plan West Part," PLZ78-391-068JR

"Nova Laser Facility, First Floor Plan East Part," PLZ78-391-069JL

"Nova Laser Facility, Mechanical Equipment Level Floor Plan," PLZ78-391-070JR

"Nova Laser Facility, Roof Plan and Details," PLZ78-391-071JN

"Nova Laser Facility, North Elevation," PLZ78-391-072JF

"Nova Laser Facility, South Elevation," PLZ78-391-073JF

"Nova Laser Facility, East and West Elevations," PLZ78-391-074JL

"Nova Laser Facility, Interior Elevations," PLZ78-391-086JB

"Nova Laser Facility, Lower Level Floor and Foundation Plan West Part," PLZ78-391-101JR

"Nova Laser Facility, Lower Level Floor and Foundation Plan East Part," PLZ78-391-102JD

"Nova Laser Facility, Exterior Wall Elevations," PLZ78-391-119JJ

"Nova Laser Facility, Capacitor Storage Racks," PLZ78-391-307D

"Nova Laser Facility, Nova Target Room" PLZ78-391-306D

"Nova Laser Facility, Target Room and Concrete Wall Elevations," PLZ78-391-109JF

"Nova Laser Facility, Building Sections, Shielding Door Schedule and Miscellaneous Details," PLZ78-391-077JV

"Nova Laser Facility, Shielding Door and Blocks Sections and Details," PLZ78-391-123JC

"Nova Laser Facility, Shielding Door Sections and Details," PLZ78-391-124JC

"Nova Laser Facility, Nova Laser Bay Ante-Room," PLA78-391-011C

"Nova Laser Facility, Target Chamber/Diagnostics Loft," PLZ84-391-001C

"Building 391, Diagnostic Loft Seismic Upgrade," PLS90-391-005E

"Building 391, Amplifier Development Lab," PLZ95-391-004DA

"Building 391, Amplab Mirror Towers," PLS96-391-003D

"Building 391, W High-Bay Conversion Optics Processing R&D Area Phase 2, First Floor Structural Plan and Details," PLS99-391-001EB

**B. Early Views:** Historic photographs of the Nova Laser reside in the LLNL Archives.

**C. Interviews:** No oral history interviews were conducted.

**D. Bibliography:**

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Weiss, Peter. "Nova Laser Now a Falling Star at Livermore Lab." *Contra Costa Times* (November 14, 1997): A12.

**E. Likely Sources Not Yet Investigated:** Information pertaining to ICF funding and policy decisions at the national level may be found in Record Group 430, Energy Research and Development Administration (ERDA) Records and in the Office of Fusion Energy/Office of Energy Research Records. There is material in both collections at DOE Headquarters in Germantown, Maryland; and at the National Archives in College Park, Maryland.

There is extensive detailed technical information on ICF laser technology in technical reports issued by the ICF Laser Program of LLNL. The scientific literature on lasers in general is vast.

**F. Supplemental Material:** None.

## Part IV. PROJECT INFORMATION

This report was prepared in 2006 by Michael Anne Sullivan and Rebecca Ann Ullrich under LLNL Memorandum Purchase Order (MPO) No. B558133 with SNL.

In 2005, LLNL and DOE/NNSA completed consultation with the California State Historic Preservation Officer (SHPO) regarding the historic significance and eligibility of Building 391 to the National Register of Historic Places. Building 391 was found eligible. This report is part of the mitigation of potential negative effects of undertakings in and around Building 391.

Large-format photographs were taken by LLNL photographer Marcia Johnson. John Bielecki and James Canoose provided building access. Tim Wieland supplied detailed information about Nova and its operations based on his extensive technical experience with it. Maxine Trost, Pat Rhiner, and Xiaorong Zhang of the LLNL Archives provided research advice, access to relevant collections, and copies of historical photographs. Barbara Sjoberg and Patty Santos provided copies of documents and photographs from the NIF Programs collections. Carol Kielusiak oversaw the project and offered extensive research support and guidance.

Figures 1 through 3 are key plans of Building 391. Original engineering drawings are located in the LLNL Plant Engineering Library. Figures 4 through 28 are historical schematics and photographs of Building 391.

Figure 1 Drawing PKB1996-391-001BG, Rev. July 2003.
FACILITY KEYPLAN, BUILDING 391, BASEMENT.

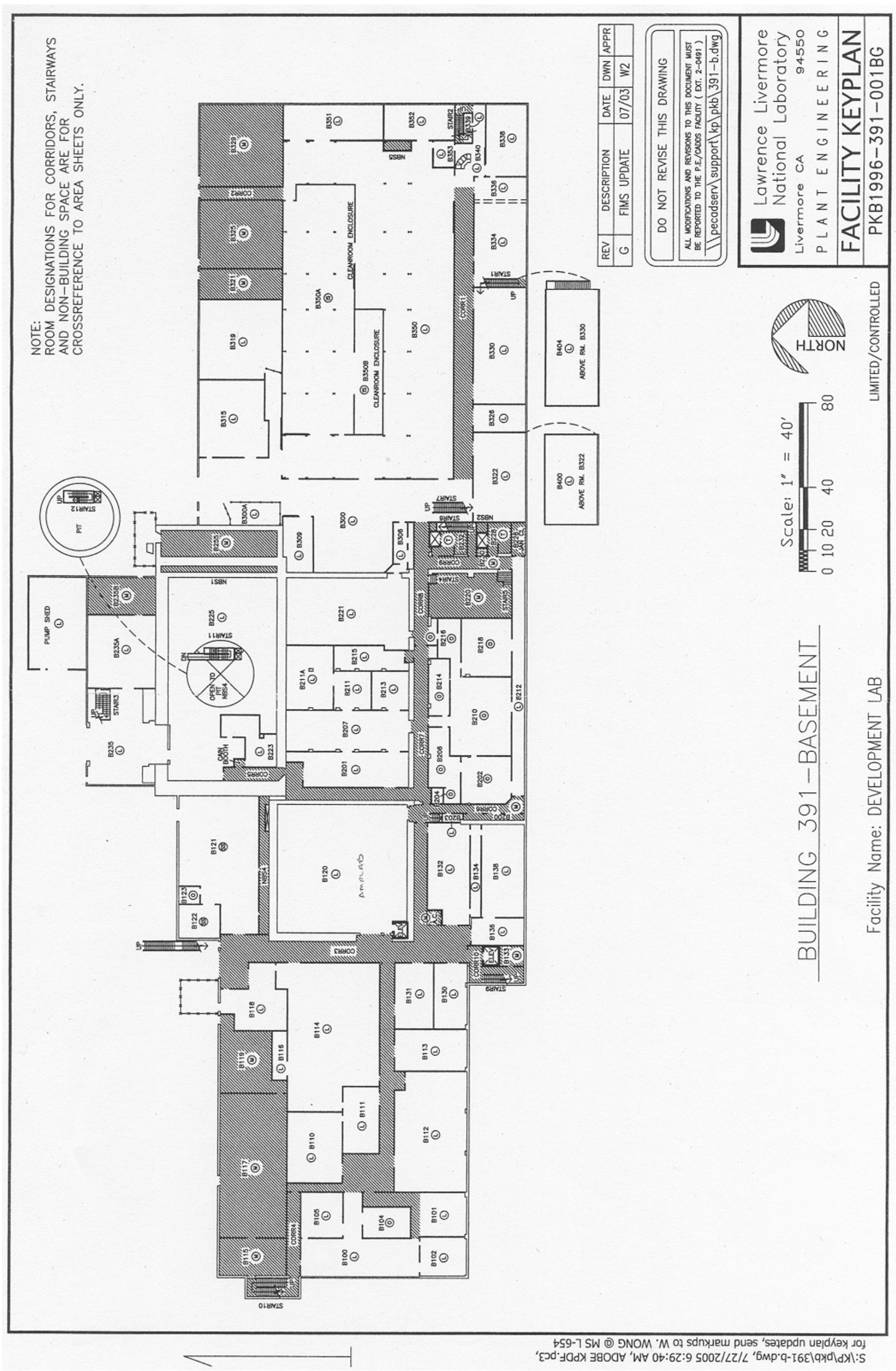

Figure 2 Drawing PKB1996-391-002BC, Rev. July 2003.
FACILITY KEYPLAN, BUILDING 391, FIRST FLOOR (WEST).

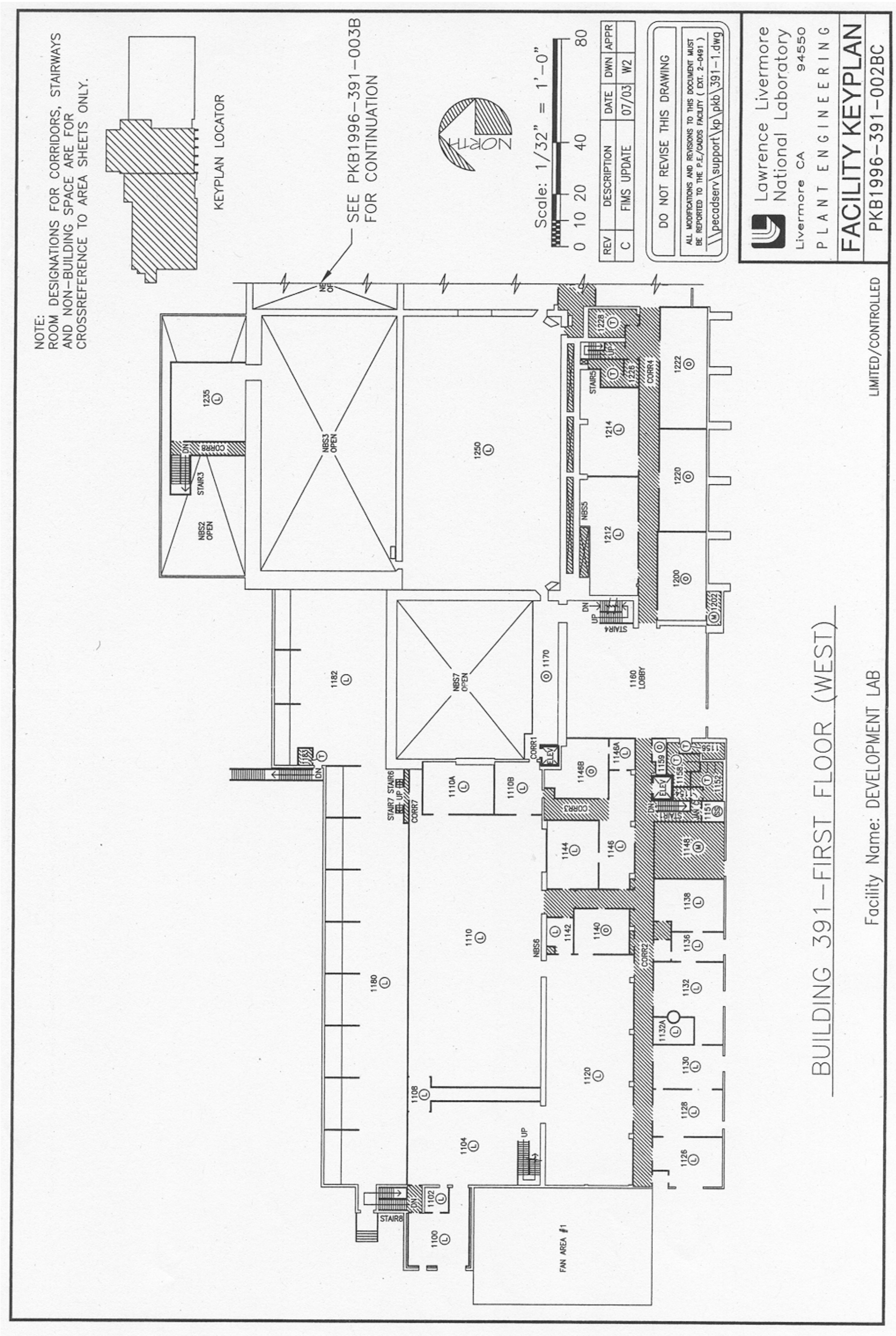

Figure 3 Drawing PKB1996-391-0003BC, Rev. July 2003.
FACILITY KEYPLAN, BUILDING 391, FIRST FLOOR (EAST).

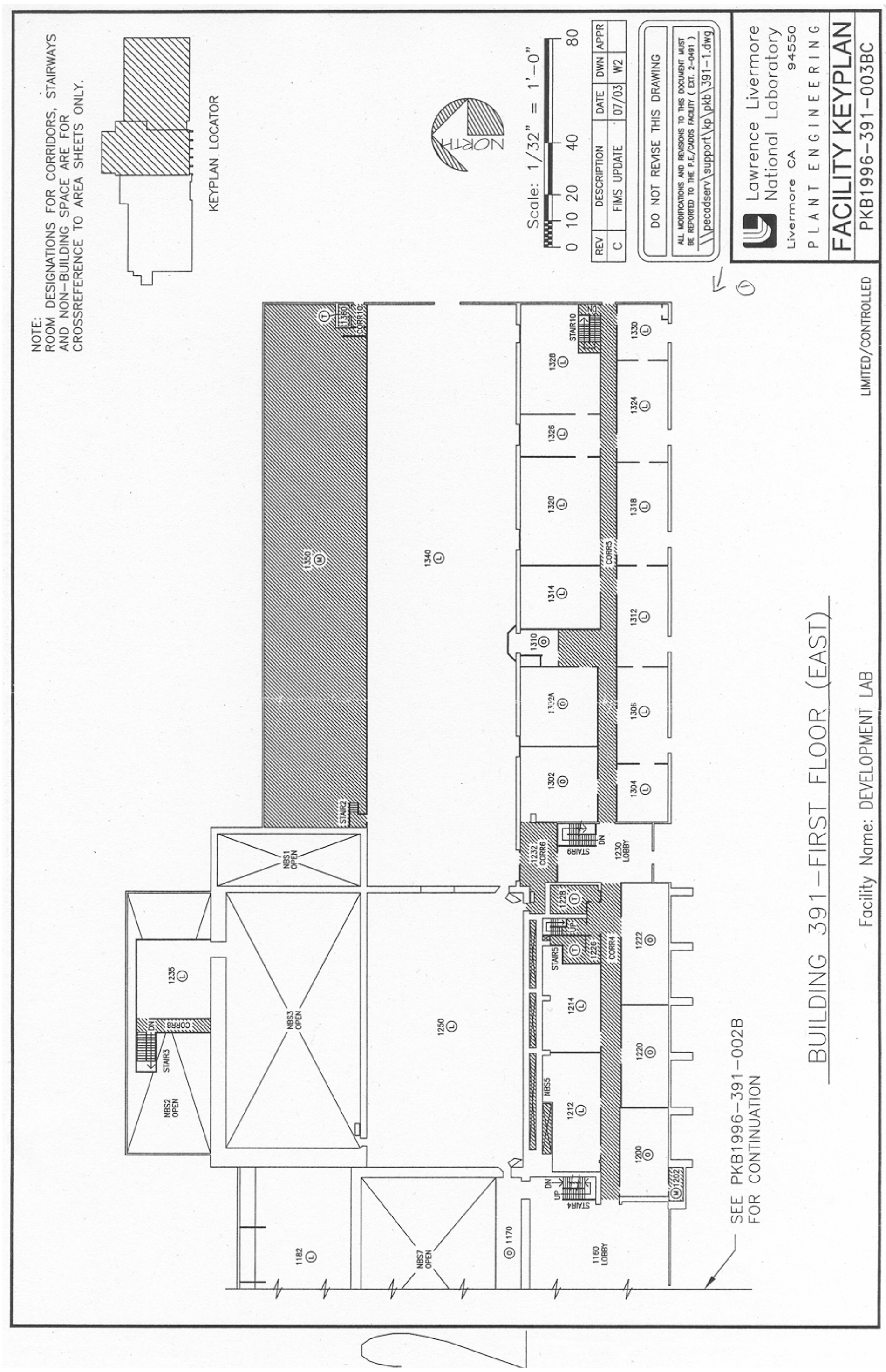

Figure 4 LLNL Archives, Box 155, Folder 11070.
SCHEMATIC OF NOVA LASER (INCLUDING TWO-BEAM) ON FIRST FLOOR OF BUILDING 391.

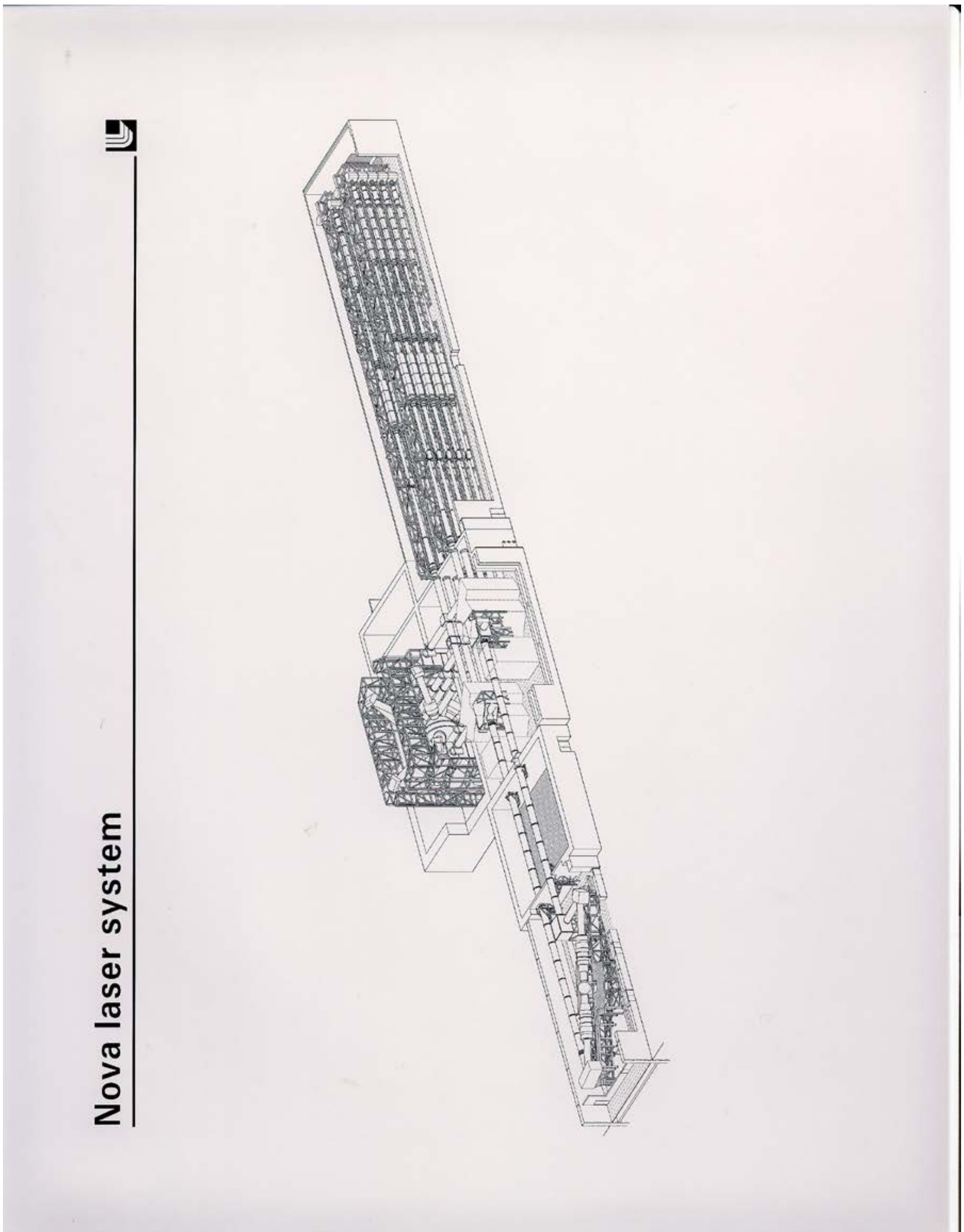

Figure 5 LLNL Archives, Box 155, Folder 11070.
CLOSE-UP OF SCHEMATIC OF NOVA LASER, SHOWING TWO-BEAM AS ASSEMBLED IN ROOM 1110, BUILDING 391.

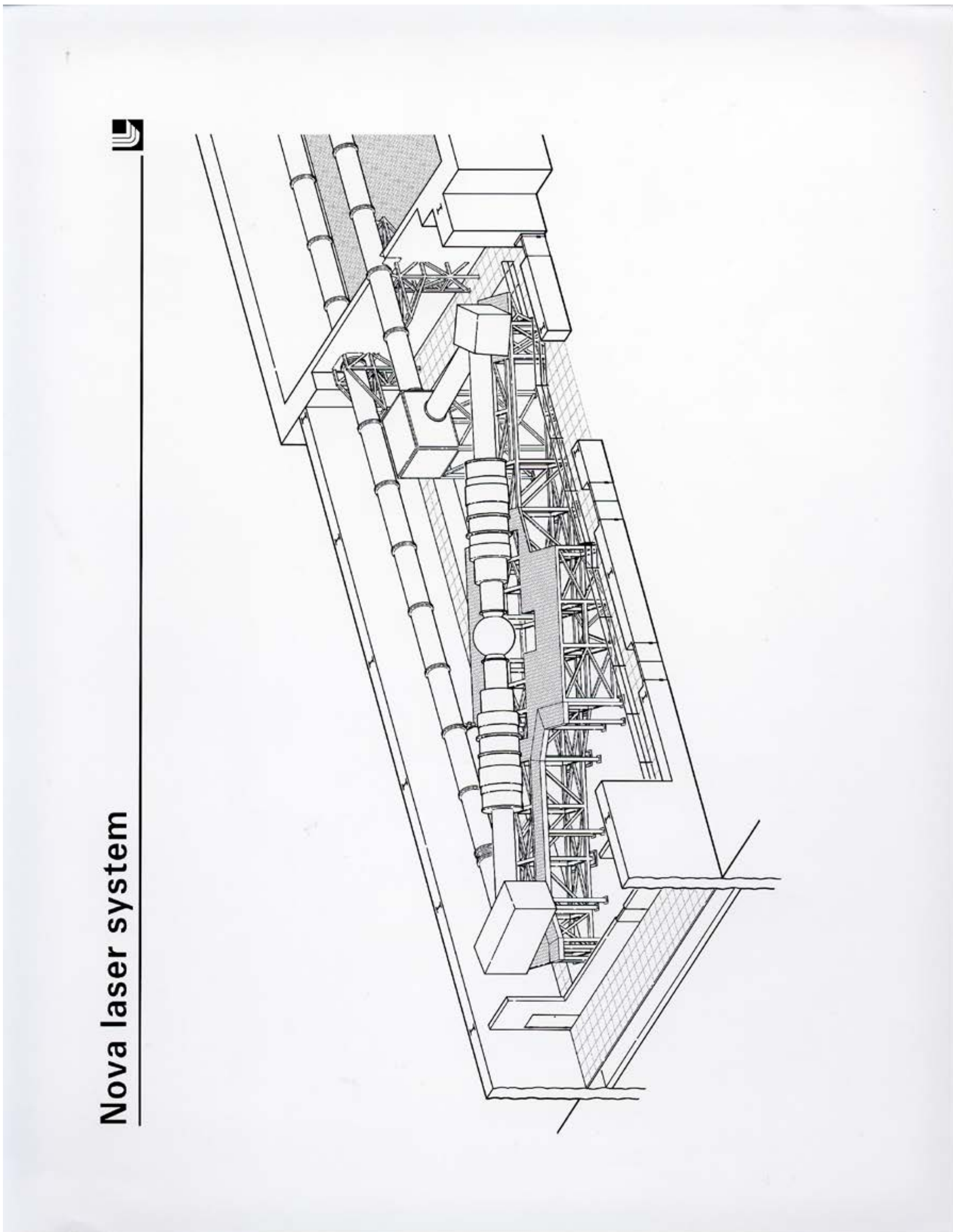

Figure 6 LLNL Archives, Box 155, Folder 11070.
CLOSE-UP OF SCHEMATIC OF NOVA LASER, SHOWING LASER ON SPACEFRAME IN LASER HIGH BAY (ROOM 1340), BUILDING 391.

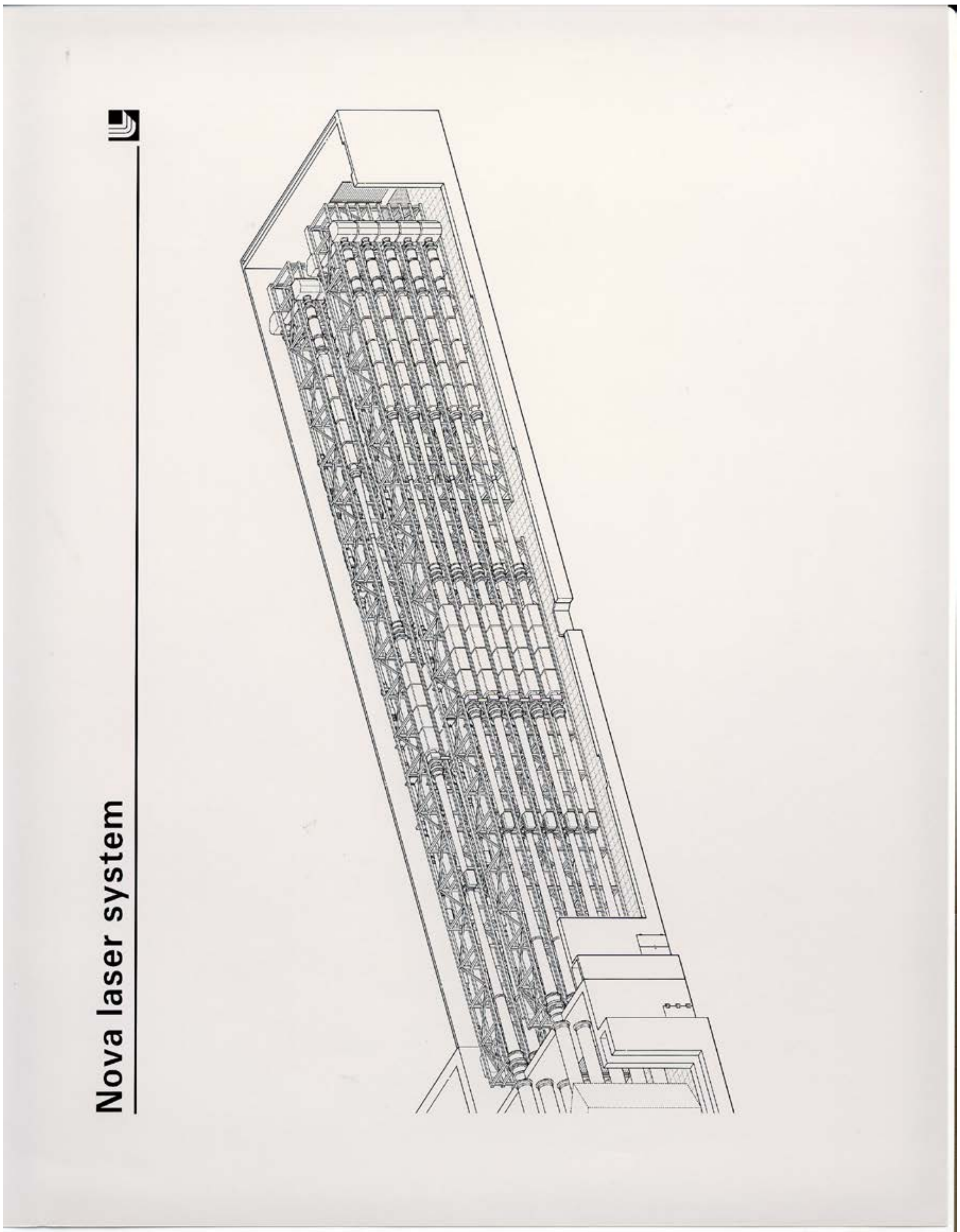

Figure 7 LLNL Archives, Box 155, Folder 11070.
CLOSE-UP OF SCHEMATIC OF NOVA LASER, SHOWING SWITCHYARD (ROOM 1250) IN FOREGROUND AND NOVA TARGET CHAMBER IN SPACEFRAME (ROOM B225), BUILDING 391.

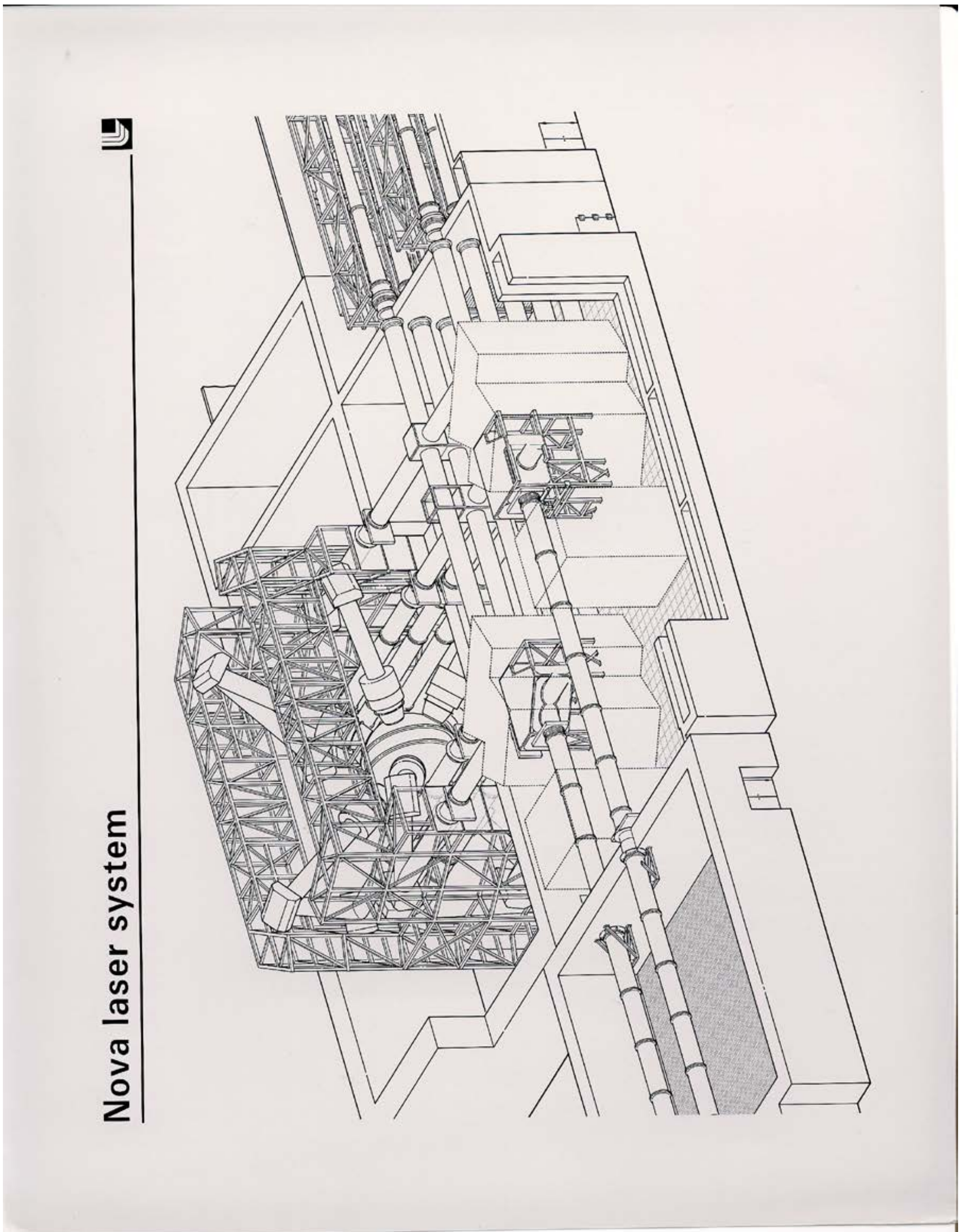

Figure 8 ARRANGEMENT OF THE MAJOR OPTICAL COMPONENTS IN A REPRESENTATIVE NOVA BEAMLINE.

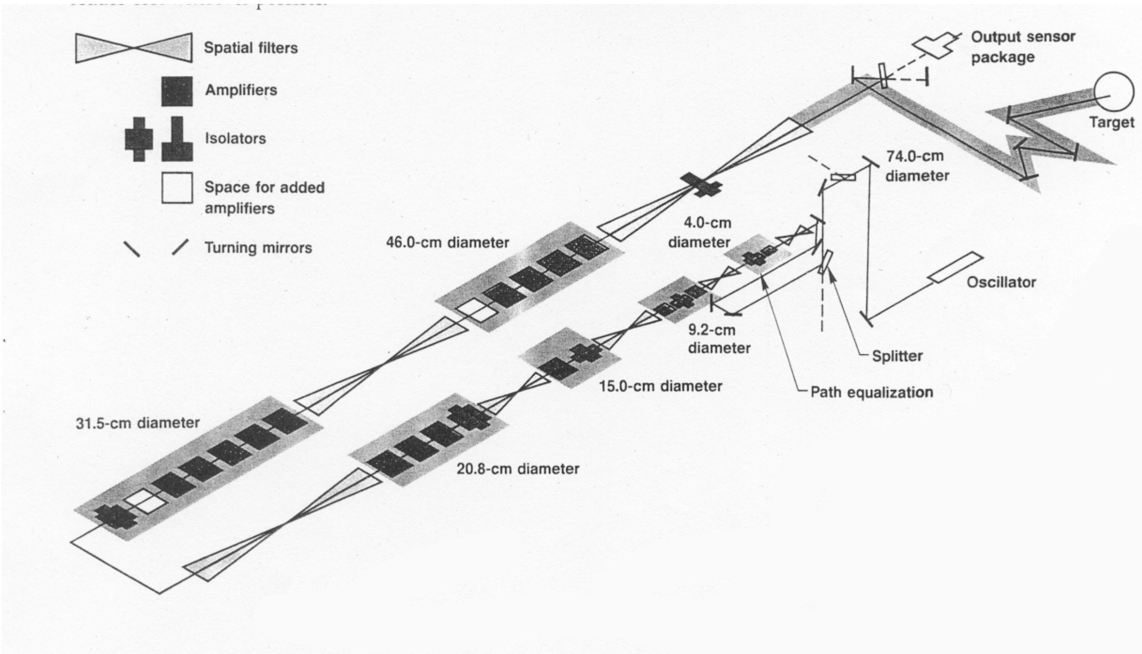

Figure 9 LLNL Archives, Box 404, Folder 13124, Photograph No. LA-1-7-83.
NOVA TARGET CHAMBER INSTALLED ON SPACEFRAME, TARGET CHAMBER ROOM (ROOM B225), BUILDING 391.

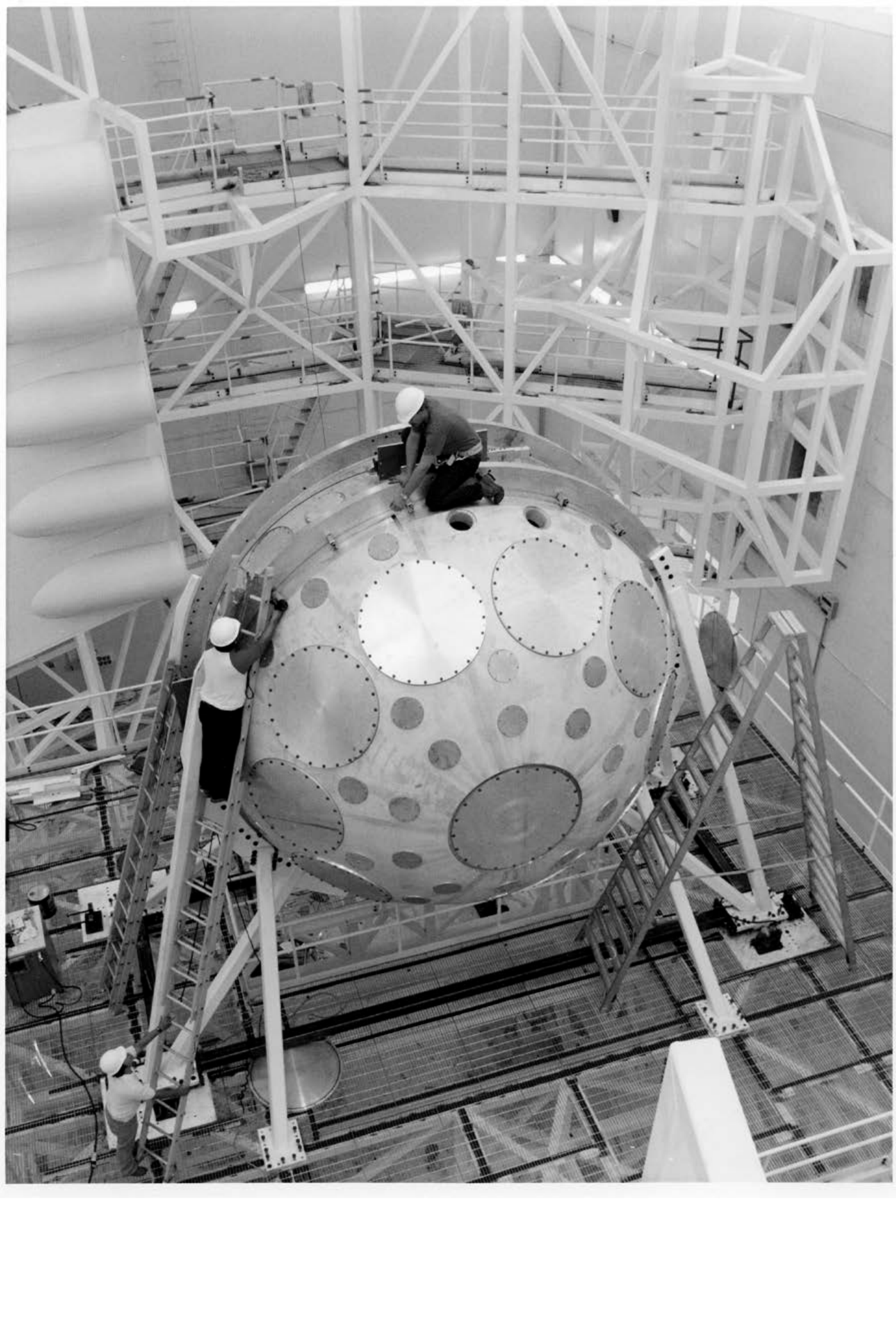

Figure 10 LLNL Archives, Box 452, Folder 13526, Negative No. 40-00-0185.
ASSEMBLING THE NOVA MASTER OSCILLATOR.

Figure 11 LLNL Archives, Box 404, Folder 13124, Photograph No. LA-1-5.1-84.
Jim Stoots, photographer, Spring 1984.
VIEW INTO 60 FOOT LONG LASER BEAM TUBE, SWITCHYARD, NOVA LASER, BUILDING 391.

Figure 12 LLNL Archives, Box 846, Folder 13026, Negative LA-1-11-85.
SPATIAL FILTERS INSTALLED ON NOVA SPACEFRAME, NOVA LASER BAY, BUILDING 391.

Figure 13 LLNL Archives, Box 452, Folder 1352.
PARTLY ASSEMBLED RECTANGULAR LASER-DISK AMPLIFIER, NOVA LASER.

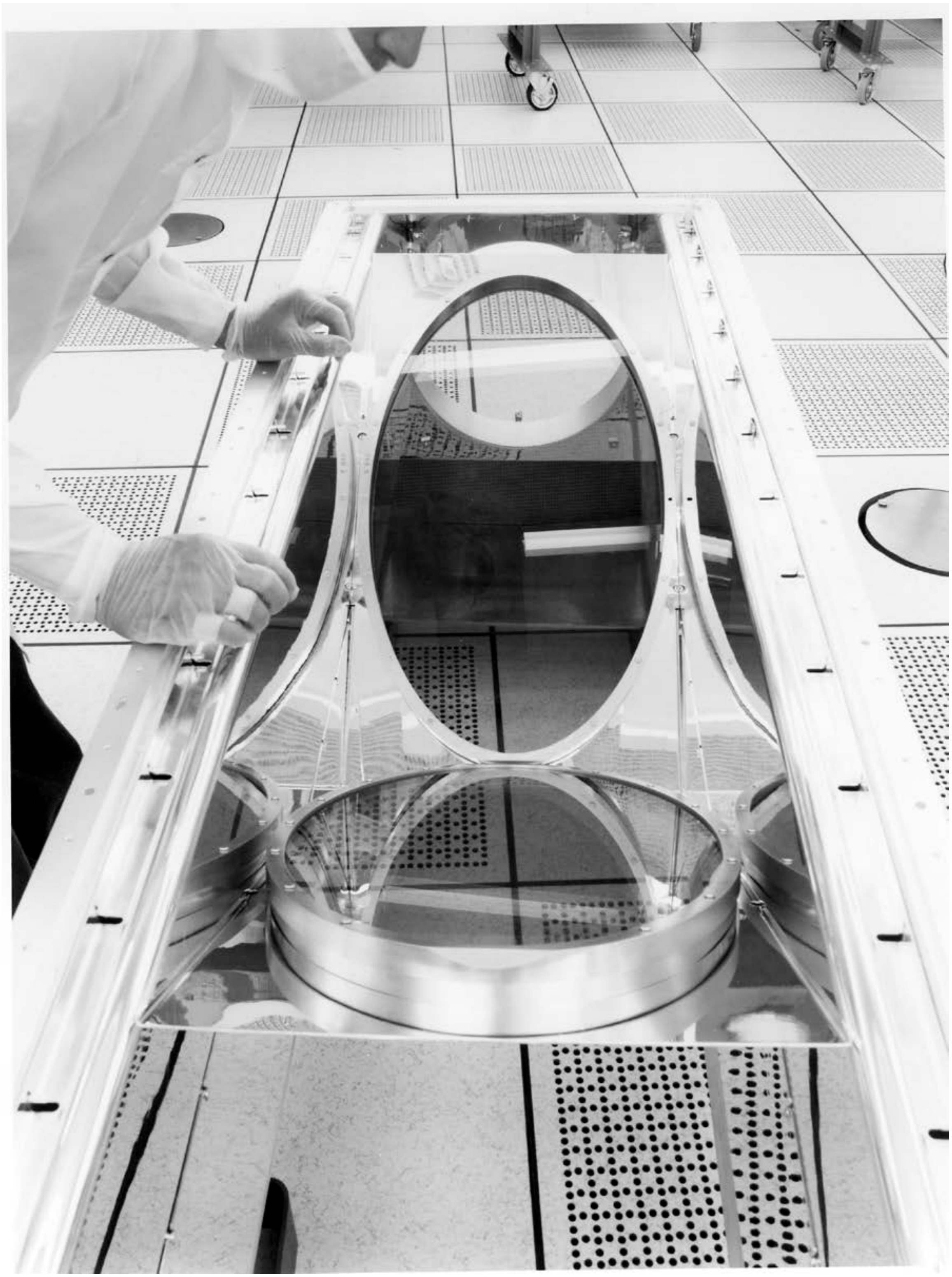

Figure 14 Lamar W. Coleman, William F. Krupke, and John R. Strack, eds., *1980 Laser Program Annual Report*, vol. 1, UCRL-50021-80 (Livermore: Lawrence Livermore National Laboratory, 1981), 2-70.
ARTIST'S SKETCH OF CROSS SECTION OF 15-CM FARADAY ROTATOR.

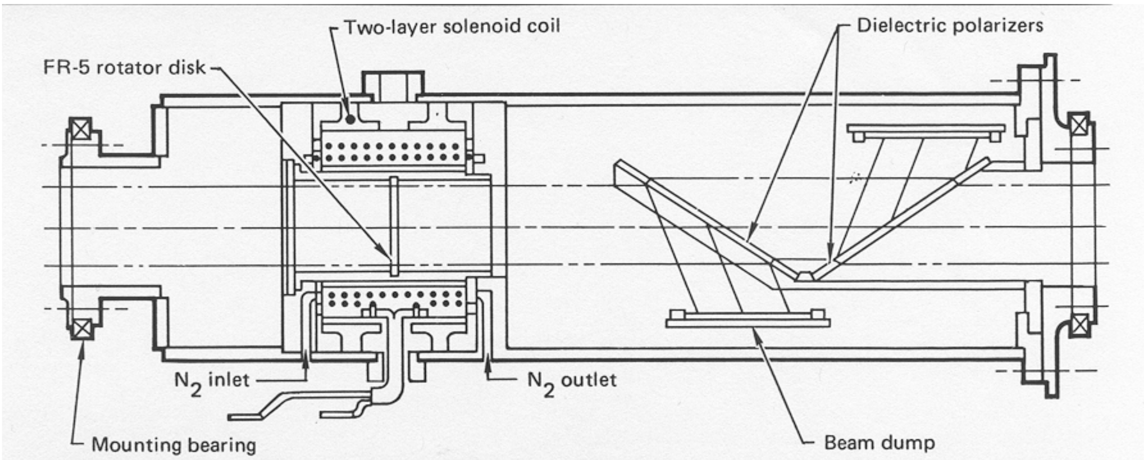

Figure 15 LLNL Archives.
BEAMLINES ON SPACEFRAME, FARADAY ROTATORS IN RIGHT FOREGROUND, AMPLIFIERS ON RIGHT IN CENTER, SPACIAL FILTERS IN LEFT FOREGROUND, NOVA LASER BAY, BUILDING 391.

Figure 16 LLNL Archives, Box 871, Folder 13105, Photograph No. LA1-1485.
Bryan Quintard, photographer, March 18, 1985.
ONE OF NOVA'S KDP CRYSTAL ARRAY ASSEMBLIES, BUILDING 391.

Figure 17 E. Victor George, ed., *Laser Program Annual Report—1981,* UCRL-50021-81, (Livermore: Lawrence Livermore Laboratory, 1982), 2-48.
ARTIST'S SKETCH OF A NOVA TURNING MIRROR MOUNTED IN ITS THREE-LEGGED GIMBAL, NOVA LASER.

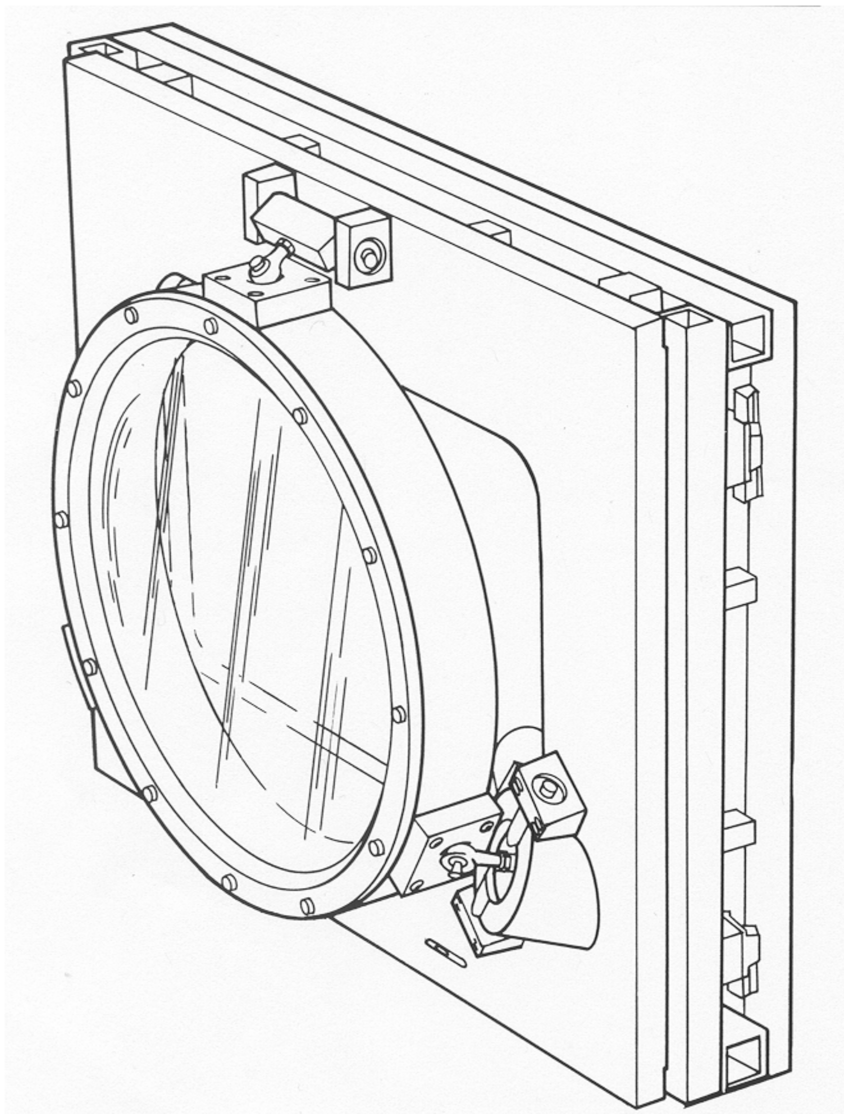

Figure 18 LLNL Archives, Box 404, Folder 13124.
VIEW OF INTERIOR OF NOVA TARGET CHAMBER; THE TARGET SITS AT THE END OF THE POINTED, PEN-LIKE ARM DESCENDING FROM THE TOP CENTER; BUILDING 391.

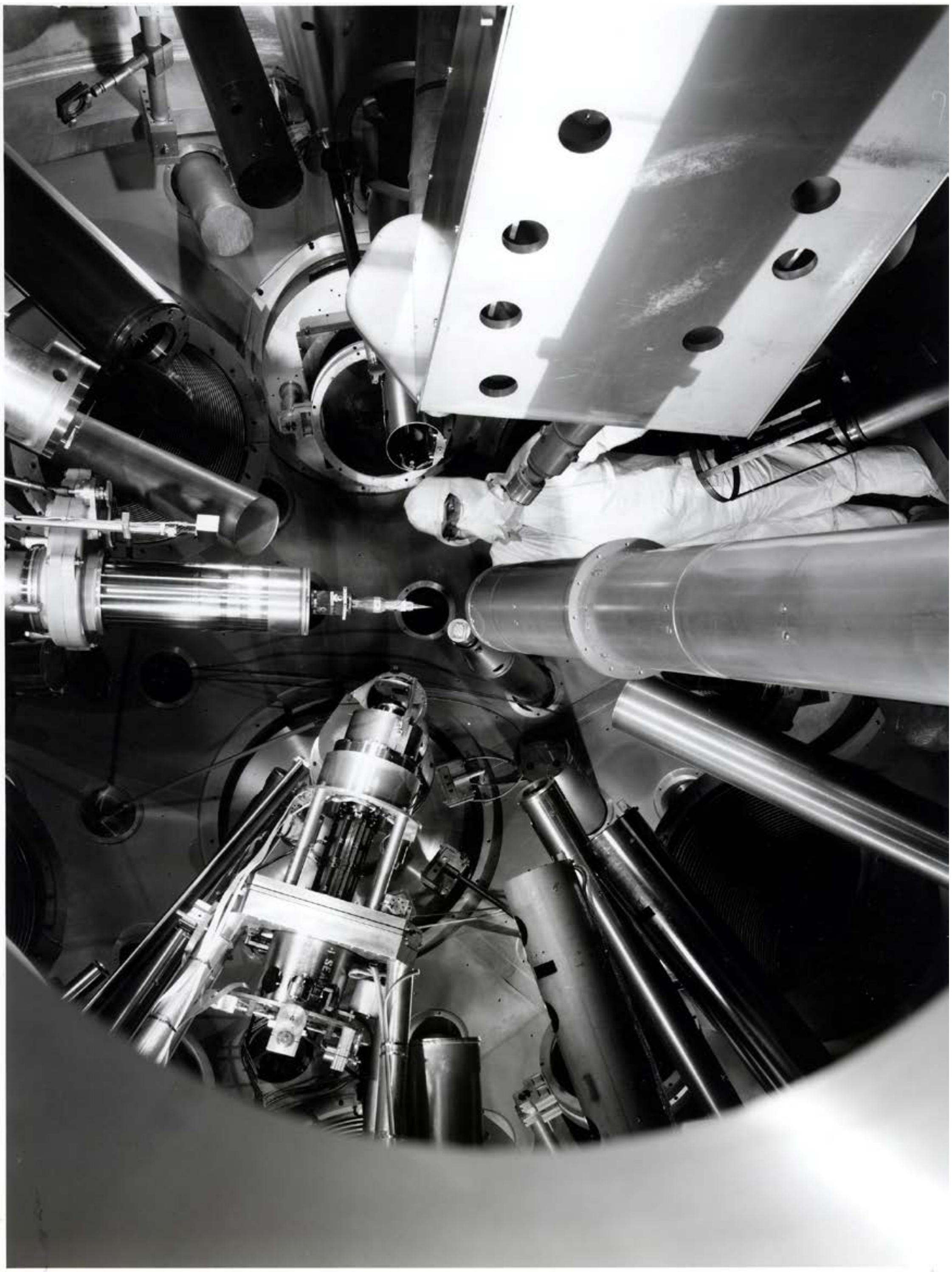

Figure 19 LLNL Archives, Box 432, Folder 13334.
TWO ROWS OF NOVA CAPACITOR BANKS, BUILDING 391.

Figure 20 LLNL Archives, Box 404, Folder 13124, Photograph No. LA-1-20-85.
Bryan Quintard, photographer, Spring 1985.
CEILING, FLOOR, CONTROL CONSOLES, AND NORTH AND EAST WALLS OF NOVA CONTROL ROOM (ROOM 1302A), LOOKING INTO NORTHEAST CORNER FROM SOUTHWEST, BUILDING 391.

Figure 21 LLNL Archives, Box 846, Folder 13026.
Bryan Quintard, photographer, Spring 1985.
NOVA LASER COMPUTERS (DEC VAX 11/780's IN FOREGROUND WITH MICROCOMPUTER SYSTEMS IN BACK), BUILDING 391.

Figure 22 LLNL Archives, Collection 086.01.01, *Newsline* Photograph Collection by Subject, Box 61: Me-Presi, Folder: Petawatt
PETAWATT COMPRESSION CHAMBER (CONTAINER WAS OBTAINED AS A USED PART AND THE METAL EXTERIOR WAS BURNISHED IN THE CLEANING EFFORTS) NEXT TO NOVA BEAMLINE, PETAWATT TARGET CHAMBER IS ON LEFT (BEHIND TECHNICIANS), NOVA TARGET CHAMBER ROOM, BUILDING 391.

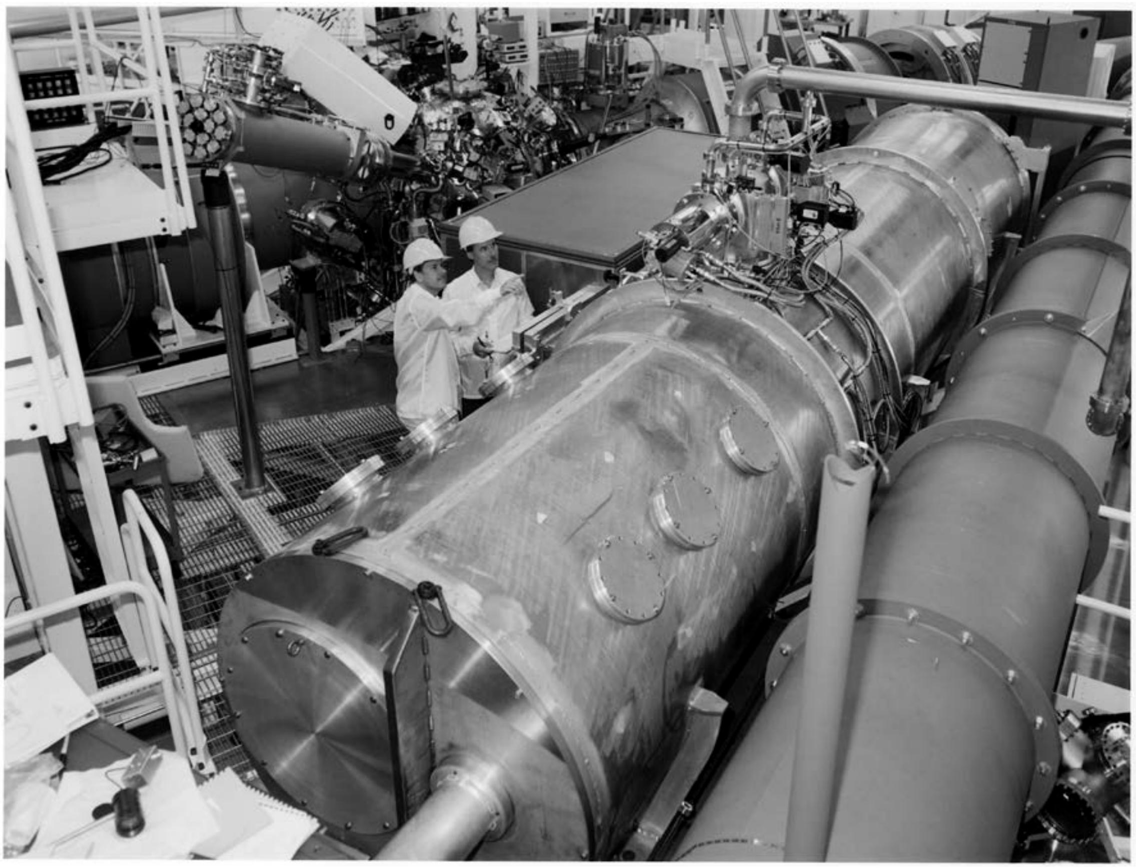

Figure 23 LLNL Archives, Box 452, Folder 13526.
NOVA TWO-BEAM CHAMBER DURING ASSEMBLY; TWO-BEAM TARGET IN CENTER; BUILDING 391.

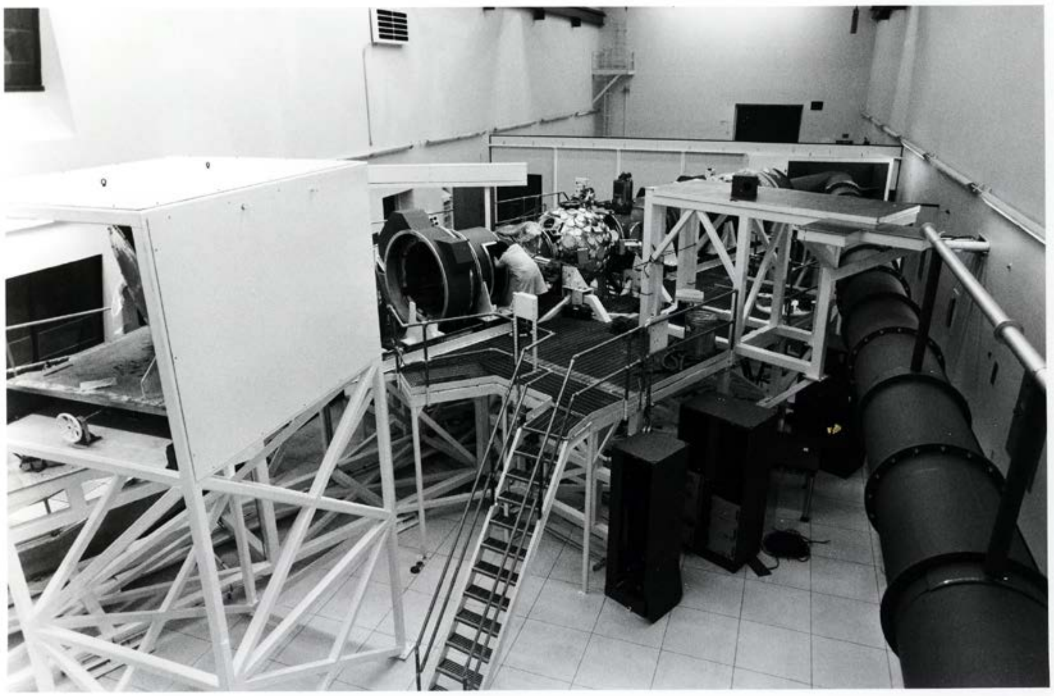

Figure 24 LLNL Archives, Box 452, Folder 13526, Negative No. GPR-7812-48. SHIELDING DOOR BETWEEN NOVA TARGET CHAMBER ROOM (ROOM B225) AND CORRIDOR TO BUILDING'S BASEMENT.

Figure 25 LLNL Archives, Box 452, Folder 13526.
SHIELDING DOORS OF NOVA TARGET CHAMBER ROOM (ROOM B225) BEFORE SPACEFRAME WAS INSTALLED; BUILDING 391.

Figure 26 LLNL Archives
NOVA LASER BAY UNDER CONSTRUCTION; LOOKING WEST TOWARD SWITCHYARD, BUILDING 391.

Figure 27 LLNL Archives
NOVA TARGET CHAMBER ROOM (ROOM B225), BASEMENT LEVEL, LOOKING SOUTH AT INTERIOR (SOUTH) WALL; SHOWING BASEMENT- AND FIRST FLOOR-LEVEL PEDESTRIAN SHIELDING DOORS (ON RIGHT); BUILDING 391.

Figure 28 LLNL Archives
LOOKING SOUTH INTO NOVA TARGET CHAMBER ROOM (ROOM B225) THROUGH SHIELDING DOORS, BUILDING 391.

**HISTORIC AMERICAN BUILDINGS SURVEY**

**INDEX TO PHOTOGRAPHS**

LAWRENCE LIVERMORE NATIONAL LABORATORY, HAER No. CA-2323
HIGH ENERGY LASER FACILITY
(Nova Building)
(Building No. 391)
7000 East Avenue
Livermore
Alameda County
California

Marcia Johnson, Photographer (1–41), May 2006

Note: Photographs 1–41 are 5” x 7” enlargements from 4” x 5” negatives.

CA-2323-1 SOUTH SIDE AND EAST END OF BUILDING 391, WITH 10’ SCALE; VIEW FROM SOUTHEAST.

CA-2323-2 EAST END OF BUILDING 391; VIEW FROM SOUTHEAST.

CA-2323-3 NORTH SIDE OF BUILDING 391; VIEW FROM NORTHEAST.

CA-2323-4 NORTH SIDE OF BUILDING 391; VIEW FROM NORTHWEST.

CA-2323-5 WEST END OF BUILDING 391; VIEW FROM WEST.

CA-2323-6 SOUTHWEST CORNER OF BUILDING 391; VIEW FROM SOUTHWEST.

CA-2323-7 WEST END OF SOUTH SIDE OF BUILDING 391; VIEW FROM SOUTH.

CA-2323-8 ORIGINAL LOBBY ENTRANCE ON SOUTH SIDE OF BUILDING 391; VIEW FROM SOUTHWEST.

CA-2323-9 CURRENT LOBBY ENTRANCE ON SOUTH SIDE OF BUILDING 391; VIEW FROM SOUTHEAST.

CA-2323-10 HALLWAY EXTENDING WEST FROM ROOM 1230, CURRENT LOBBY, BUILDING 391; VIEW FROM EAST.

CA-2323-11 ROOM 1230, CURRENT LOBBY OF BUILDING 391, ENTRANCE ON SOUTH (EXTERIOR) WALL; VIEW FROM NORTHWEST.

CA-2323-12 ROOM 1230, CURRENT LOBBY OF BUILDING 391, NORTH WALL AND ENTRY TO NOVA LASER BAY; VIEW FROM SOUTHEAST.

CA-2323-13 NORTH AND EAST WALLS OF EAST END OF ROOM 1222, OFFICES, BUILDING 391; VIEW FROM WEST.

CA-2323-14 NORTH AND EAST SIDES OF ROOM 1160, ORIGINAL LOBBY, INCLUDING STAIRWAY, PARTITIONS, DOORS, AND SECOND-FLOOR RAILING, BUILDING 391; VIEW FROM SOUTHWEST.

CA-2323-15 SOUTH END OF CORRIDOR 3 WITH UTILITY CABLE AND PIPING ALONG CEILING, BASEMENT, BUILDING 391; VIEW FROM NORTHWEST.

CA-2323-16 BEAMLINE OF FORMER TWO-BEAM NEAR CEILING, BUILDING 391; VIEW FROM WEST DOOR.

CA-2323-17 FORMER BEAMLINE PERFORATIONS THROUGH EAST WALL OF AMPLAB (ROOM B120), BUILDING 391; VIEW FROM WEST.

CA-2323-18 SPACEFRAME FOR TARGET CHAMBER, TARGET CHAMBER ROOM (ROOM B225), BASEMENT LEVEL, BUILDING 391; VIEW FROM WEST.

CA-2323-19 SOUTH END OF HALLWAY BETWEEN BASEMENT LEVEL OF TARGET CHAMBER ROOM (ROOM B225) AND BASEMENT CORRIDOR, INCLUDING FORMATION FOR SHIELDING DOOR TO FIT INTO WALL, BUILDING 391; VIEW FROM NORTH.

CA-2323-20 NORTH SIDE OF SHIELDING DOORS BETWEEN BASEMENT LEVEL OF TARGET CHAMBER ROOM (ROOM B225) AND ROOM B235, BUILDING 391; VIEW FROM NORTH.

CA-2323-21 SOUTHEAST CORNER OF ROOM B235, INCLUDING EAST SHIELDING DOOR OF TARGET CHAMBER ROOM (ROOM B225), BUILDING 391; VIEW FROM NORTHWEST.

CA-2323-22 May 10, 2006.
EMERGENCY SMOKE EXHAUST SWANSON PANEL ON NORTH SIDE OF CORRIDOR 8 IN BASEMENT OF BUILDING 391; VIEW FROM SOUTH.

CA-2323-23 May 10, 2006.
NORTH-CENTRAL SECTION OF FORMER CAPACITOR BANK ROOM (ROOM B391); VIEW OF CLEAN ROOM ENCLOSURE (ROOMS B350A AND B350B) FROM SOUTHWEST CORNER OF ROOM, BUILDING 391.

CA-2323-24 May 10, 2006.
SOUTH SECTION OF FORMER NOVA CAPACITOR BANK ROOM (ROOM B350), BUILDING 391; VIEW FROM WEST.

CA-2323-25 May 10, 2006.
POWER RACKS AND CONTROL PANEL (ROOM B340) FOR COMPONENT TEST LABORATORY (ROOM B338), BUILDING 391; VIEW FROM WEST.

CA-2323-26 May 10, 2006.
PEDESTRIAN AND ROLL-UP DOORS ON NORTH EXTERIOR WALL OF BASEMENT, WEST OF ROOM B315, BUILDING 391; VIEW FROM SOUTHEAST.

CA-2323-27 May 9, 2006
HALLWAY EXTENDING EAST FROM ROOM 1230, CURRENT LOBBY, BUILDING 391; VIEW FROM WEST.

CA-2323-28 May 12, 2006.
OFFICE PARTITIONS AND MURAL ON NORTH WALL OF ROOM 1302A, BUILDING 391; VIEW FROM SOUTH.

CA-2323-29 May 11, 2006.
SOUTH SIDE OF SOUTH SECTION OF SPACEFRAME AND SOUTH WALL OF NOVA HIGH BAY (ROOM 1340), BUILDING 391, WITHOUT SCALE; LOOKING NORTHEAST FROM ENTRY AREA.

CA-2323-30 May 12, 2006.
VIEWING GALLERY IN CENTER OF SOUTH WALL OF NOVA HIGH BAY (ROOM 1340), AS SEEN FROM INSIDE HIGH BAY, BUILDING 391; VIEW FROM WEST.

CA-2323-31 May 12, 2006.
NOVA HIGH BAY (ROOM 1340), EAST END OF SOUTH SIDE OF SOUTH SECTION OF SPACEFRAME WITH MOST COMPONENTS REMOVED, 3 FARADAY ROTATORS VISIBLE ON TOP # BEAMLINES, BUILDING 391; LOOKING NORTHEAST FROM SOUTH WALL.

CA-2323-32 May 15, 2006.
NOVA HIGH BAY (ROOM 1340), LOOKING WEST BETWEEN THE TWO SECTIONS OF THE SPACEFRAME, SHOWING NORTH SIDE OF SOUTH SECTION AND SOUTH SIDE OF NORTH SECTION OF SPACEFRAME, BUILDING 391.

CA-2323-33 May 10, 2006.
MOUNTING CRADLE FOR NOVA TARGET WITH PETAWATT TARGET CHAMBER VISIBLE BEHIND (EAST OF) CRADLE IN CENTER OF PHOTOGRAPH, TARGET CHAMBER ROOM, BUILDING 391, WITH 10' SCALE; VIEW FROM WEST.

CA-2323-34 May 12, 2006.
ENTRANCE INTO TARGET CHAMBER ROOM FROM NORTHWEST CORNER OF SWITCHYARD, BUILDING 391, WITHOUT SCALE; VIEW FROM SOUTHEAST.

CA-2323-35 May 15, 2006.
EAST WALL OF SWITCHYARD (ROOM 1250), ROLL-UP DOOR AND BEAMLINE PERFORATIONS THROUGH WALL TO NOVA LASER BAY, BUILDING 391; LOOKING EAST FROM INTERIOR OF SWITCHYARD.

CA-2323-36 May 15, 2006.
MIRROR IN TURNING MIRROR TOWER, SWITCHYARD (ROOM 1250), PERFORATIONS FOR BEAMLINES BETWEEN SWITCHYARD AND TARGET CHAMBER ROOM ON NORTH WALL (ON RIGHT OF PHOTO), BUILDING 391; VIEW FROM SOUTHEAST.

CA-2323-37 May 15, 2006.
LOOKING WEST INTO SWITCHYARD (ROOM 1250) WITH TURNING MIRROR TOWERS, BUILDING 391.

CA-2323-38 May 15, 2006.
VIEW OF EAST END OF NOVA HIGH BAY (ROOM 1340), INCLUDING NORTH WALL OF HIGH BAY AND NORTH SIDE OF NORTH SECTION OF SPACEFRAME, BUILDING 391; VIEW FROM WEST.

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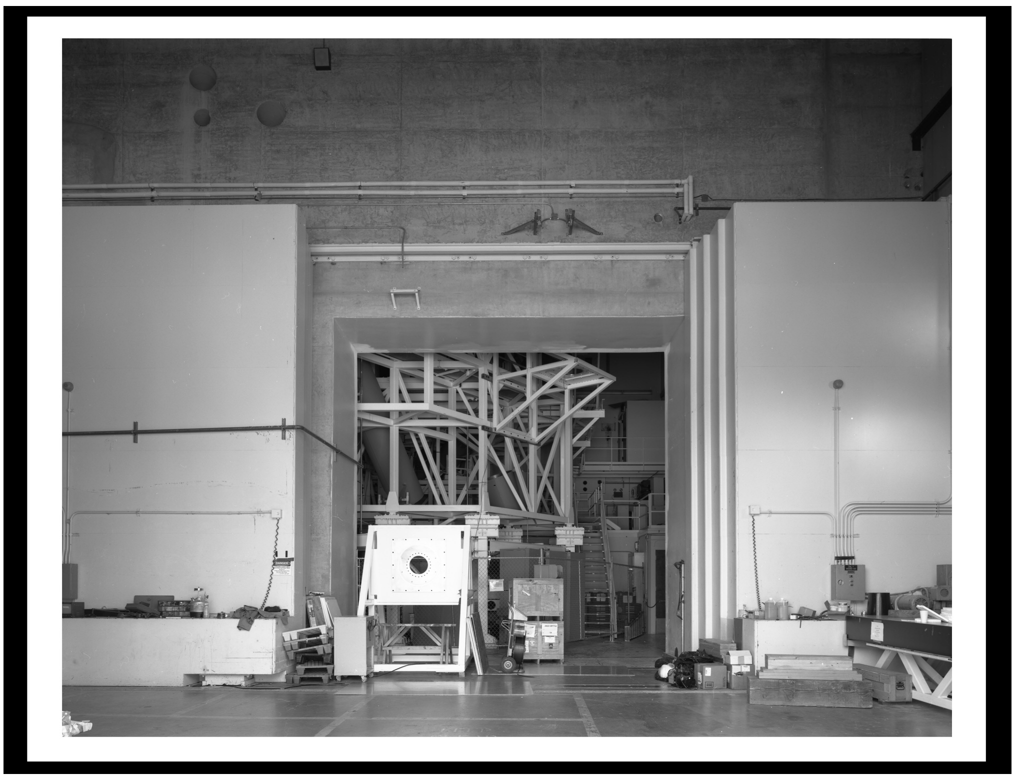

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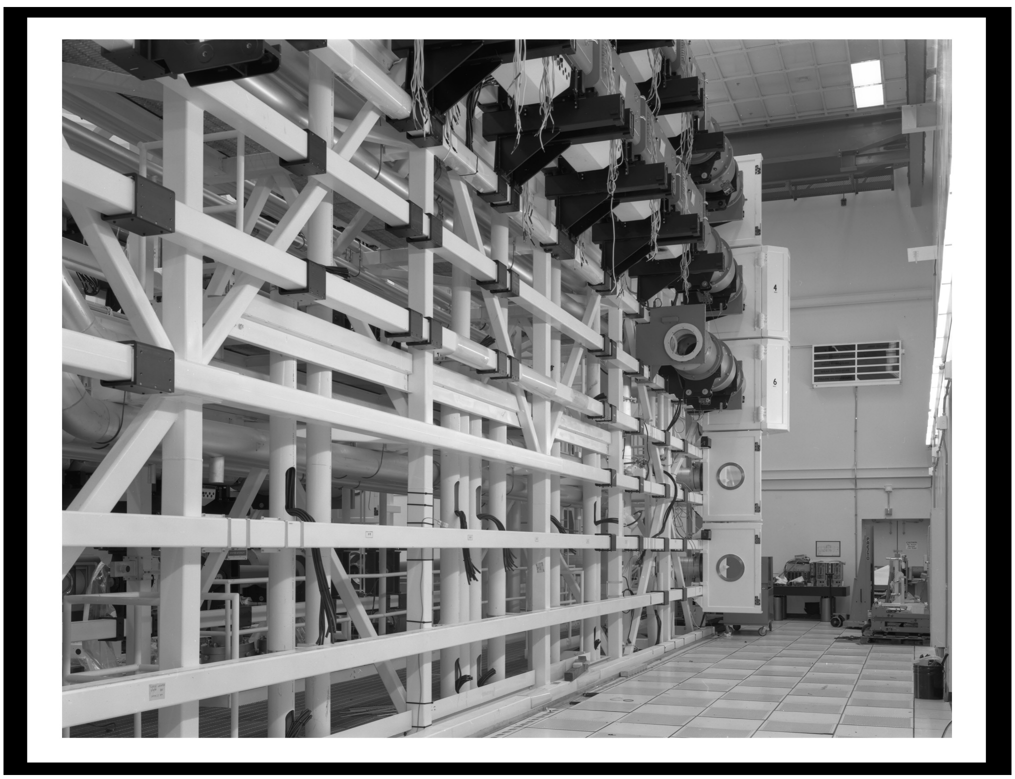

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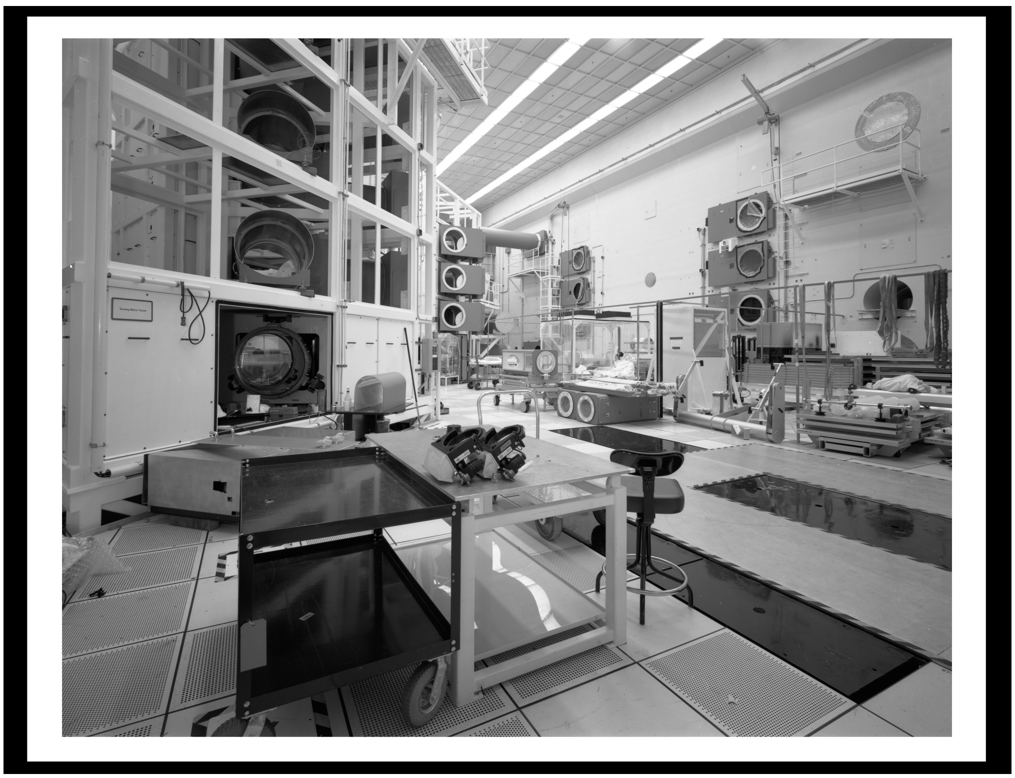

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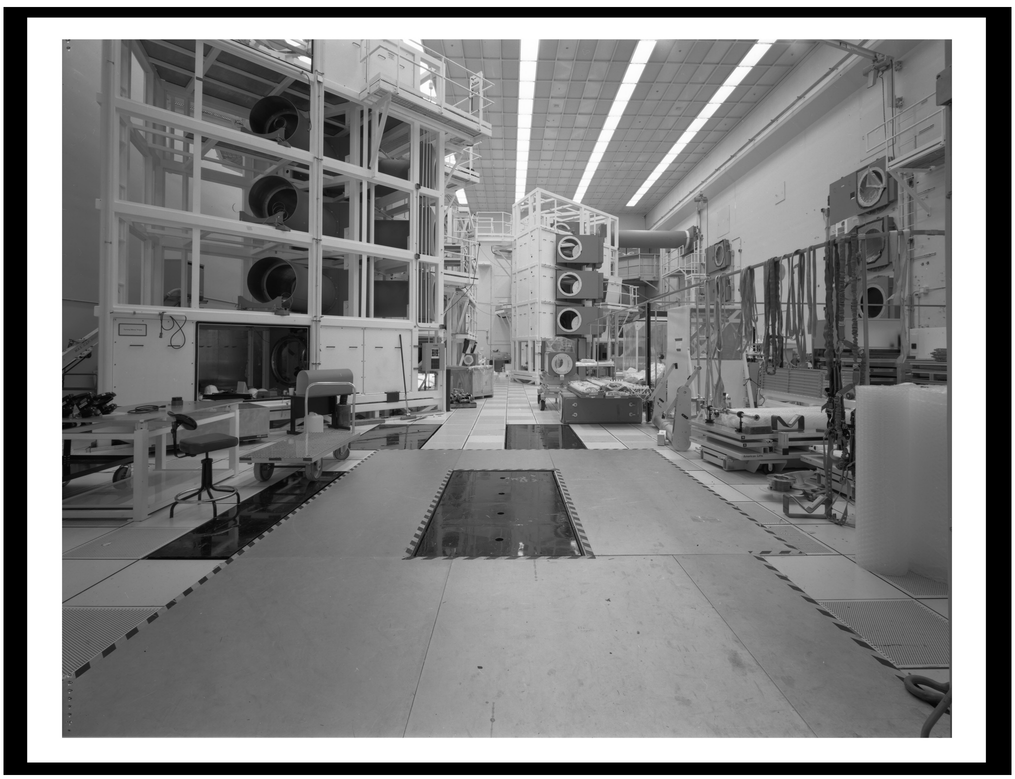

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